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25th ANNIVERSARY ISSUE

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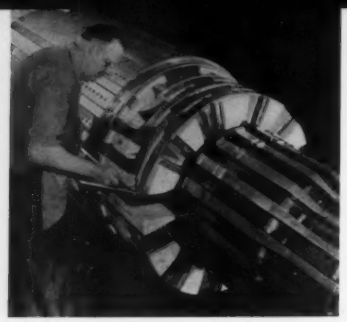
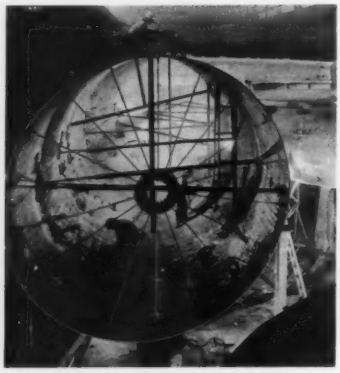
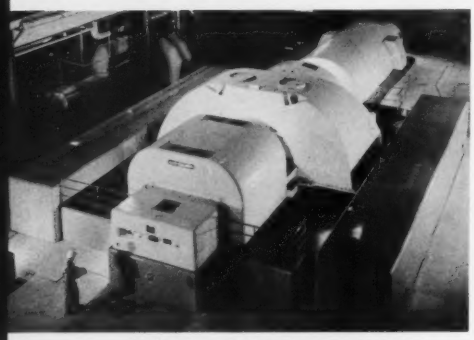


SUPERCHARGED COOLED GENERATORS

Quarter Century Chronicle of Engineering Progress . . . The Allis-Chalmers Electrical Review



MAJOR PUMP STORAGE PROJECTS



NUCLEAR POWER FROM FISSION

FUEL CELLS PRODUCE POWER

As we mark the 25th Anniversary of the Allis-Chalmers ELECTRICAL REVIEW, we realize how fortunate we have been for the opportunity to record the tremendous expansion of engineering and scientific achievements during the past quarter century.

Engineers and scientists at Allis-Chalmers have contributed in great measure to expanding mankind's horizons. Many of these achievements are documented in the pages of this publication that spans these dynamic years. The many authors who have contributed generously to the engineering art by recording these developments and providing helpful information are recognized throughout industry.

Scientific information now available on new power sources gives promise that the energy needed for a major expansion of our industrial world is assured. Automatic machines and system components developed in recent years are rapidly bringing full automation of complete processes. New optimum designs of major equipment are now being made with the aid of intricate computers and certain experimental designs can now be simulated and checked in computer laboratories.

Today's power industry is just a step away from million-kw generating units. Transformer ratings are ten times what they were twenty-five years ago. The steel industry will soon be cold rolling up to 8000 ft per minute. It will be automatically measured and controlled so that thickness variations can be held to one-ten thousandth of an inch. Measurements are made with non-destructive and non-contacting instrumentation. Cement industry's amazing growth has brought them to 12,000 barrels per kiln per day. Raw materials varying widely in analysis will be automatically blended to meet exacting requirements. These trends are paralleled in all fields of industry.

This has been an exciting quarter century. We at Allis-Chalmers have been proud to share with you this challenging period and look forward to still greater accomplishments to record in our ELECTRICAL REVIEW.

W. S. Scholl

W. G. SCHOLL
Executive Vice President

25th ANNIVERSARY

ALLIS-CHALMERS Electrical REVIEW

THE COVER

TWO HIGH SPEED MOTORS with an efficient gear drive, in place of a single slow speed motor with ring gear and pinion drive, are being supplied for large grinding mills. The method of balancing load between motors is given in the article on page 10, "Grinding Mills Get New Drive System."

Allis-Chalmers Staff Photo by Harold Shrode

Allis-Chalmers

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DOES THE GOVERNMENT PAY FOR INVENTIONS?

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General Patent Attorney
and
HOUSTON L. SWENSON
Patent Department
Allis-Chalmers Mfg. Co.

When entering into government development contracts, either prime contractors or subcontractors may lose valuable rights to normal commercial use of their products or to certain trade secrets. Here are facts to consider.

In recent years the number of research and development contracts granted to industry and financed by the United States government has increased greatly. As might be expected, there has been considerable competition between companies in obtaining these contract awards. However, as corporations become more involved in government contracting they likewise become more aware of the presence and significance of the pitfalls encountered concerning inventions.

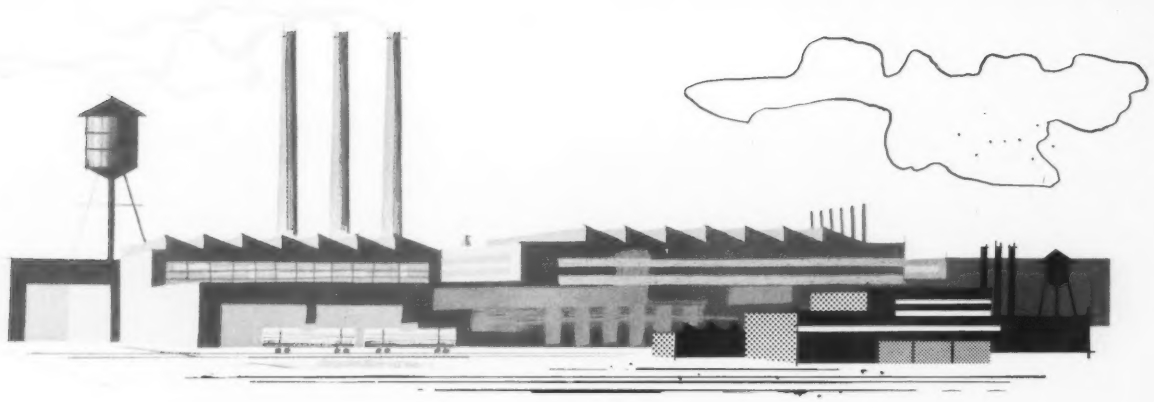
There are two major reasons for the misunderstanding that commonly exists. A frequently heard and apparently a prime reason is the false premise that the government pays for and should own the inventions resulting from federally financed research and development. A second reason is that many people, including government personnel, do not understand the nature of the government research and development undertaken by industrial concerns.

Actually, our government does not contract with industrial concerns to produce patentable inventions. Such contracts are for the prime purpose of obtaining new technical or scientific information, a new product or a new process.

Concerns must be qualified

Industrial concerns are requested to bid for or negotiate such contracts not because they are either big or small business, but because of their having adequate facilities, competent personnel, background know-how, a current interest and possibly an established preferential position in the same or related commercial field. In general, the concern getting the contract is either the low bidder or the one deemed best qualified to timely and efficiently perform the contract. The same price is paid whether or not patentable inventions result and if the information or product or process sought after is obtained, the contractor has fulfilled his obligations.

For many years, a number of our government agencies adopted a patent policy of acquiring only a paid-up, nonexclusive license for governmental purpose. Title to inventions made in the performance of government financed research and development contracts remained with the contractor. The nonexclusive license to the government specifically excepted giving the government the right to furnish services and supplies to the general public in competition with the contractor and its licensees. Thus, although the contractor could not collect royalties from a competitor supplying the government with his patented article made in the performance of a government contract,



the contractor could prevent a competitor from supplying the article to nongovernmental groups. In other words, the contractor still had his competitive advantage in the commercial field.

However, during the latter part of World War II, there was considerable agitation in Congress for the government to adopt a policy of acquiring title to all inventions made in the performance of government financed research and development. With the passage of the Atomic Energy Act in 1946, a major deviation in government contract terms was achieved. At this time, national security was a primary concern and there was little significant industrial development in the atomic energy field. Thus the act provided that inventions made by anyone having a relationship with the Atomic Energy Commission and which are useful in the utilization or production of atomic energy for special nuclear material shall be deemed to have been made by the government.

By 1954, the possibility of peaceful uses of atomic energy had been well recognized. Consequently, the Atomic Energy Act was revised for the purpose of encouraging broader participation in the development of atomic energy with the hope of encouraging industry to more effectively participate in such development. However, the changes introduced did not release the government from taking title to the mentioned inventions. Consequently, it turned out to offer no inducement for industry to more actively participate in the development of peacetime uses of atomic energy.

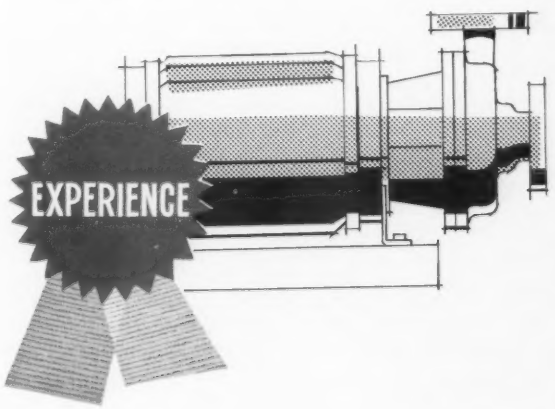
Between 1954 and 1958, legislation was passed affecting rights to inventions when dealing with certain other government agencies. Generally speaking, the legislation states that whether the government or the contractor retains title to the invention is determined at the discretion of the agency director. The likelihood of a director permitting title of an invention to remain with the contractor is remote since the director is always subject to the criticism of allowing an individual to take something away from the public.

The National Aeronautics and Space Act of 1958 states that inventions resulting from research financed from NASA shall be the exclusive property of the United States unless title or a portion thereof is waived by the administrator. Just as in the early days of atomic energy there was a belief that little of general commercial interest would be developed under NASA contracts. Once again it has not taken industry long to realize that a large share of such inventions are merely improvements over their present commercial products.

Recently, there have been revisions of the less harsh regulations of the Department of Defense which suggest a trend toward government ownership of inventions made in performing government financed research. These revisions have particularly centered on inventions in a field of new technology or one in which there has been no significant private or industrial development. These DOD terms are still preferable to the AEC or NASA terms.

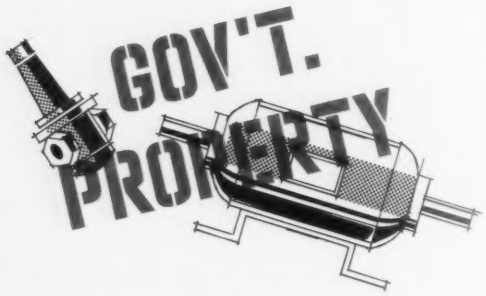
Pressure for government ownership continues

In 1960 a number of bills were introduced dealing with the matter of government ownership of inventions resulting from government financed research and development. One of these bills would set a uniform policy for all government agencies. It provides that the U. S. shall have exclusive right and title to any invention made by any person in the performance of any obligation arising from a contract or lease executed or grant made by or on the behalf of an executive agency and is directly related to the subject matter of such contract. Likewise, title and exclusive right go to the U. S. or invention resulting from



any activity undertaken in the performance of services under any contract or lease executed or grant made by or on behalf of an executive agency for work involving scientific or technological research development or exploration.

With the above bill, the trend concerning the ownership of inventions conceived or first actually reduced to practice in the performance of government financed research has nearly reached its pinnacle. The tendency on the part of Congress and many government agencies, in fact practically all of them, is for the government to acquire greater rights and in many instances title to such inventions. A general reason expressed by those behind this trend is that the government has financed the inventions resulting from government research and development contracts and therefore should own the inventions. These backers further state that with government ownership the public will receive full benefit from the inventions they have paid for. The argument that what the government pays for the government should own seems to be a pretty convincing one.



Commercial developments lost

It was not until industry started operating under various rules and regulations which bind federal agencies that the full effect of such regulations was understood. Improvements on off-the-shelf commercial items such as a valve or motor may become the property of the government if first actually used in fulfilling a contract with a federal agency such as the Atomic Energy Commission. With the government ownership, the contractor's competitors may copy the article and place it on the market in competition with the contractor's units. Since the government has not paid for tools, equipment, training, salary, security and fringe benefits, the contractor naturally balks at the idea that the government should own the invention.

Instances in which the invention is a potentially commercial item is the rule rather than the exception. A patent on an impractical or useless thing, apart from increasing our technology, is of no value. However, if the patented article appears to have commercial significance, government ownership is no assurance that any attempt will be made to develop a marketable product. Since government ownership traditionally means free licensing, protection against copying is destroyed. Consequently, the contractor who loses title to his invention no longer has incentive to invest the time, effort and money usually necessary for the development of a commercially

usable product. Small business which may rely heavily on patent protection is particularly affected in this manner.

One approach used by some businesses to avoid loss of title to their inventions has been to negotiate the matter with the federal agency prior to entering into a contract. Partly because of statutory restrictions this has been effective only to a limited degree with certain government agencies. The Atomic Energy Commission has determined that no contractor can have an established patent position in the field of atomic energy. Thus, the Commission has rarely granted waiver of title. At the most, a contractor can hope to occasionally obtain the sole right to license use of an invention which only indirectly relates to the use or production of atomic energy. Some contractors have obtained these "successes" by negotiating for the retention of outfield rights to inventions pertaining to specifically itemized commercial products, i.e. the exclusive right except as to the government to use the invention for purposes other than the utilization or production of atomic energy.

Subcontractors have less chance to negotiate

As subcontractors, businesses are receiving an even more severe impact from this legislative trend. These subcontractors greatly exceed the number of prime contractors. The likelihood of a subcontractor's inventions relating to commercial products is much greater. Furthermore, the hands of a subcontractor are tied. There is untold pressure for him to accept a subcontract on the same terms concerning inventions that exist between the prime contractor and the government agency. Thus, he has no opportunity for negotiating with the government agency. His burden is much greater as he must scrutinize the prime contract in addition to the proposed subcontract.

It is apparent that industry is faced with another complication in considering government research and development contracts. For those who are indifferent about the disposition of title of their inventions there is no problem. For those concerns which rely heavily on patents, their future may depend largely on the success of numerous groups now advocating a change in this legislative trend.

PORTABLE TRANSFORMERS SHORTEN SERVICE INTERRUPTIONS

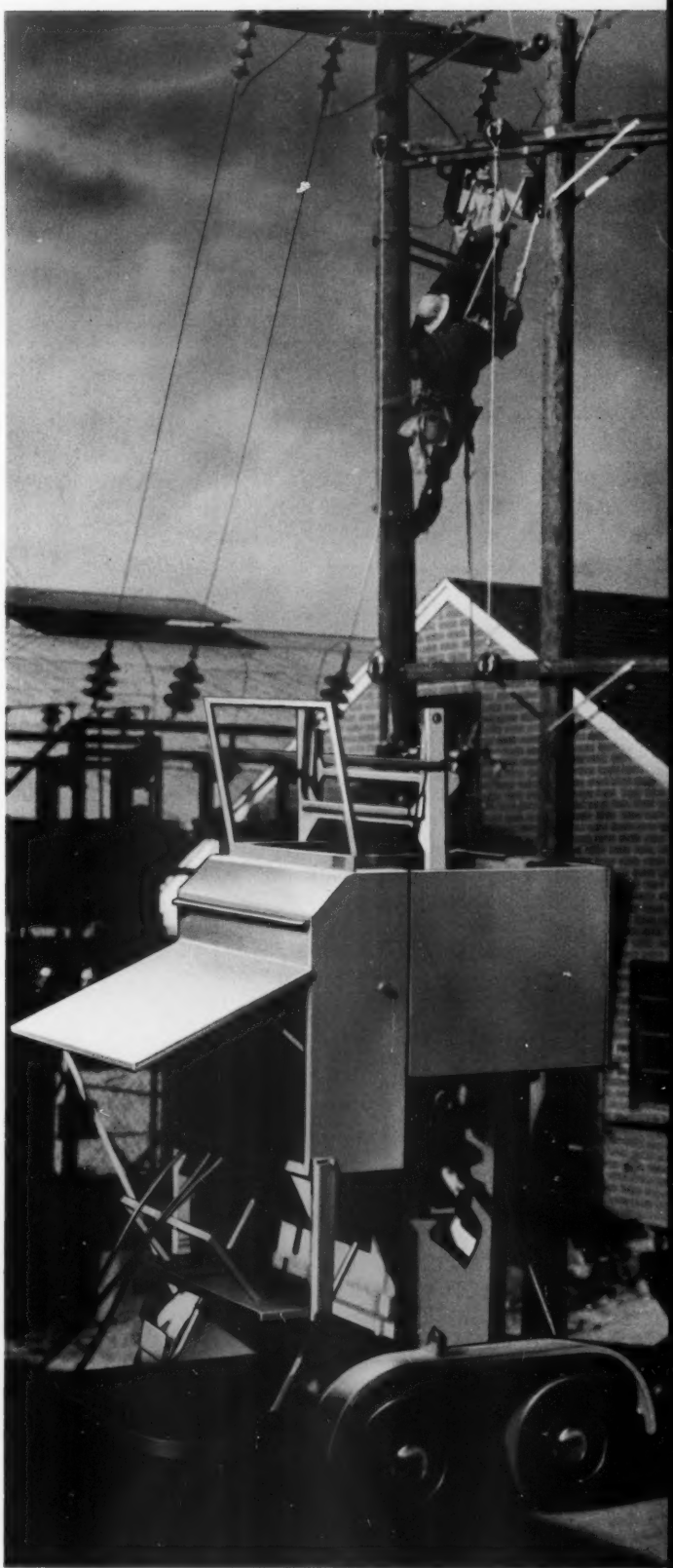
G. T. FINGER
Distribution Section
Duke Power Co.
and
A. L. BAXTER
Pittsburgh Works
Allis-Chalmers Mfg. Co.

Versatile units using series-multiple transformers provide needed variety of voltage.

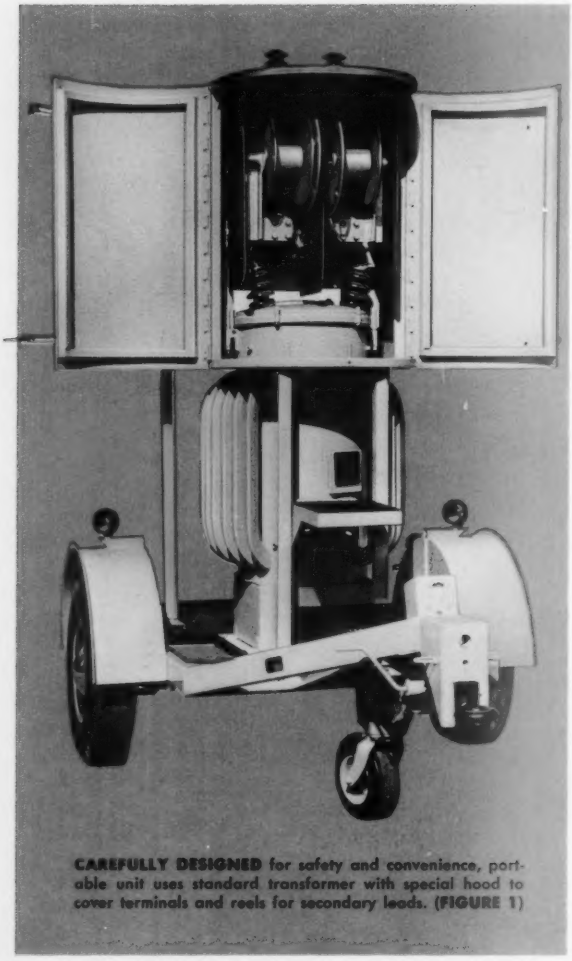
A NUMBER OF TRAILER MOUNTED PORTABLE TRANSFORMERS are now being used by Duke Power Co. for restoring or maintaining service during maintenance operations.

Four years ago the series-multiple transformer came into increased usage in the electrical industry with the advent of the externally operated series-multiple switch. This type of transformer serves the function of allowing utilities to change sections of their system from a lower voltage to a higher voltage with a minimum of interruption time. The need to go to higher primary voltages on distribution lines has arisen from higher loads and, consequently, higher line losses and poorer regulation. The wide use of the series-multiple transformer has also been aided by the acceptance by the industry of the use of no-tap transformers.

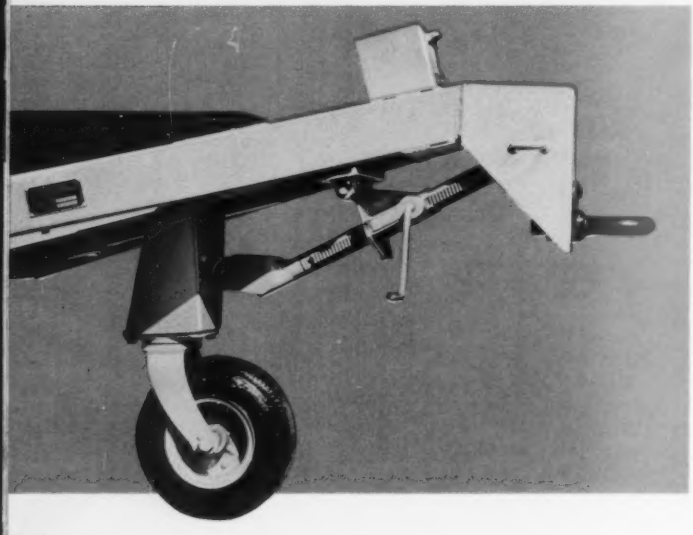
Since the portable units had to be adaptable for operation at many points on a utility system, various voltage combinations were required. The dual voltage switch provides speed and simplicity in changing voltages, thus reducing outage time.



ROLLED IN WHEN NEEDED, portable transformers speed maintenance operations.



CAREFULLY DESIGNED for safety and convenience, portable unit uses standard transformer with special hood to cover terminals and reels for secondary leads. **(FIGURE 1)**



FRONT WHEEL makes unit easy to roll into position and keeps it level. Standard SAE pintle rings are used to hitch the unit to utility's service or line truck. **(FIGURE 2)**

Restoring or maintaining service

In case of distribution transformer failure, the service is interrupted and must be restored as quickly as possible and the transformer replaced. With change out for overload, relocation, repair, voltage change, or other cause, service has not been interrupted and the transformer must be replaced with little or no interruption to service.

Handling "change out" for overload, relocation, repair or voltage change presents a slightly different problem and involves a planned service interruption. Interruptions are usually scheduled at the customer's convenience. Some customers may indicate that they cannot tolerate an interruption long enough to change transformers or that the interruption should be made on a Sunday or some unusual time when the crew is not regularly on duty. However, most customers would likely consent to an interruption of just a few seconds.

By wheeling out a portable transformer and connecting it into the system while the old transformer is removed and replaced by a new one, only a few seconds interruption at two intervals are required.

Standard pole-type units used

When a distribution transformer failed, the ordinary procedure was to locate a replacement unit and assign a service or line crew the task of transporting the replacement unit to the location and removing the faulty unit. With small transformers this procedure is still the only proper solution. However, where larger transformers are involved, heavy duty transportation and a suitable line crew may not be readily available, and delays might result. The remedy for this situation is the portable distribution transformer which can be easily wheeled out to the location, connected and placed in service in minutes.

A portable distribution transformer uses a standard pole-type unit mounted on wheels with a metal hood on the top portion of the transformer to house the wire reels and cover the high and low voltage terminals, as shown in Figure 1.

The two new models of two-wheel portable distribution transformers were developed and 62 are now in operation on the system. One model is rated 100 kva, single-phase, 2400 by 7200/12470Y to 120/240 volts and has an externally operated switch to change from 2400 to 7200 volts. The unit is of the protected type and the secondary breaker is used to assist in load transfer. The other model is rated 150 kva, three-phase, 4180 by 12540 to 216Y/125 volts dual primary voltage with an externally operated switch to change from 4180 to 12540 volts. Like the single phase units, it is also of the protected type, with the secondary breaker used to assist in load transfer. Secondary cables on these portable transformer units consist of 5341 strand 4/0 welder's cable wound on independent non-magnetic reels mounted just above the secondary terminals of the transformer.

These portable transformers are rather unique in design in that a single front wheel is provided as shown in

Figure 2 so that the unit can be rolled around by two men. At the rear of the transformer, a rear deck is provided for a man to stand on when connecting the low voltage cables and to act as an outrigger to prevent the unit from turning over backwards. The high voltage leads are stored on reels in the high voltage compartment and swinging doors are provided so the reels are readily accessible. The cable feeds through a hollow porcelain bushing in the cover. The needed length can be threaded through and locked as desired. Normally, 50 ft of cable is provided.

Units stored ready for operation

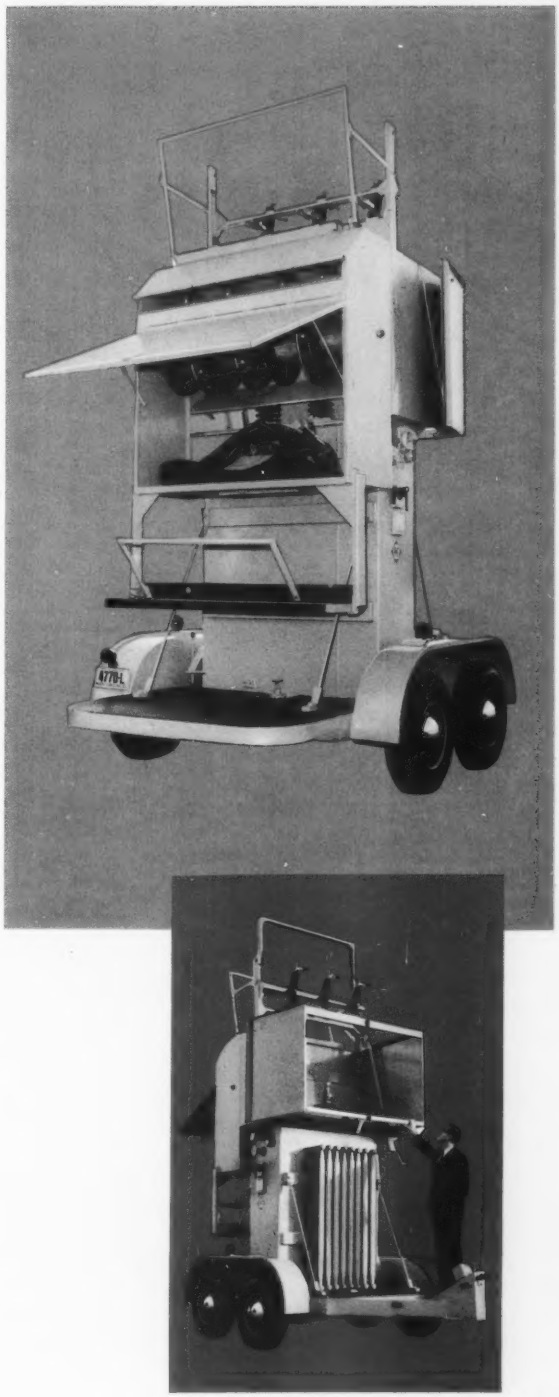
The portable transformer units are stored at Service Centers and are provided with two standard SAE pintle rings, one for use with 22 in. height pintle hooks on three-quarter and one-ton service trucks and one for 29 in. height pintle hooks on three-ton line trucks. In case of need, the portable transformer can be handled by a two-man crew. It is merely attached to the towing vehicle and towed to the location and wheeled into exact location by hand, if necessary. The primary dial switch is set to desired primary voltage. The secondary cables are reeled off and attached to secondary and to transformer secondary terminals. Primary cables are attached to primary directly or by means of an auxiliary crossarm. The load is then connected or transferred by means of the low voltage breaker handle to the portable transformer and service is thereby restored. Simple instruments are used to check polarity and phase relations.

These portable transformers are so arranged and lighted that they can be connecetd in service and left overnight without danger. All high voltage leads and terminals are enclosed in the hood. The top of the hood is out of reach except by step ladder. Secondary leads are well insulated and are out of ordinary reach.

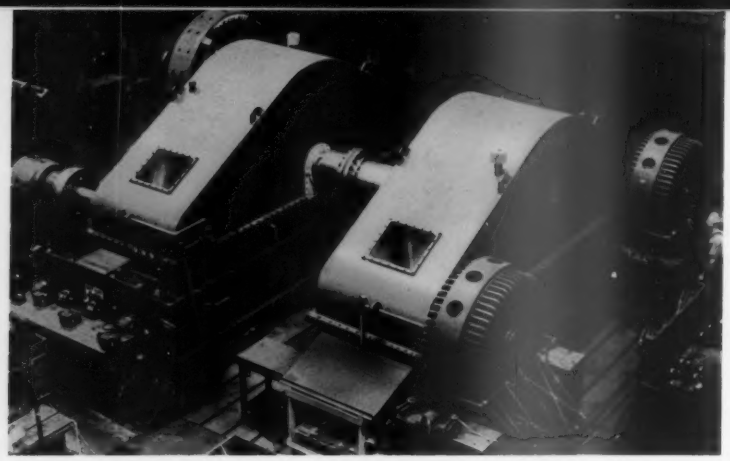
The Duke Power Co. has completed the development of and is now using several 500-kva three-phase portable transformers rated 22,900 volts delta to secondaries of either 480Y/277 or 208Y/120 volts. These units are similar to the 100-kva and 150-kva units except that they are mounted on a chassis with a tandem axle, as shown in Figure 3. The units presented a special problem as overall height could not exceed 12 ft 6 inches to meet North and South Carolina highway regulations.

Maintaining electric service to customers is becoming more important and more difficult because customers are demanding and are dependent upon better service. Interruptions to service that were tolerated a few years ago would be considered inexcusable today. The modern air-conditioned buildings of today are lighted and ventilated by electrical apparatus and are unusuable if electric service is interrupted. Service interruptions can be caused by many different factors.

These portable transformers are an excellent solution to solve the problem of providing better service to the ultimate users and to cut power interruption time to an absolute minimum. ◆

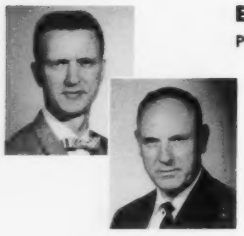


TANDEM AXLE is used with larger three phase ratings. Deck at front and rear simplify making connections. (**FIGURE 3**)



NEW GRINDING MILL DRIVE, "Twinducer," proven in unusual test. Driven by two 800-hp, 450-rpm, synchronous motors, drive is coupled to duplicated drive transmitting power to test generators. Drive efficiency averaged 98.5 percent.

GRINDING MILLS GET NEW DRIVE SYSTEM



E. J. KLOVERS
Processing Machinery Dept.
and
A. C. SEIDL
Motor and Generator Dept.
Allis-Chalmers Mfg. Co.

Savings in initial cost, erection, operation and maintenance are gained with new grinding mill drive, using two synchronous motors.

Recent increases in mill size have created a problem of obtaining an efficient low cost drive system. The answer is a new balanced gear reducer using high speed motors.

Conventional drives on existing mills have a ring gear which encompasses the mill shell. The problem with such gears is that a ring gear with a wide face and from four to six feet larger in diameter than the mill shell is required. Such a gear casting or weldment is necessarily expensive and the single reduction ratio demands a driving motor operating between 150 and 240 rpm. Unfortunately, the larger the mill, the slower the mill speed and the slower the speed required of the drive motor.

Because of the trend to larger mills and associated design problems, a new drive arrangement was developed using a double reduction gear box and two high speed synchronous motors. With considerably larger mill drives requiring motors rated 2500 hp or higher, the first cost comparison indicates that a ring gear and pinion and its driving motor cost somewhat more than a drive having a double reduction gear box and two higher speed motors.

The use of two motor rotors mounted on the driving pinion shafts permits placing the motors on the mill side of the drive, greatly reducing the overall length of the mill. The gearing and bearings within the gearbox are lubricated by both internal oil and automatic pressure systems.

The application of two synchronous motors mechanically interconnected to a single load is somewhat unusual. This application is not difficult, although to obtain proper load division between the two motors, certain factors must be considered in the design of the motors.

Load angle is the key

A synchronous motor, while operating at constant speed regardless of load, does exhibit a change in the relative position of the synchronously rotating field of the rotor and the rotating magnetic field of the stator. Under various loads this relative position or "load angle" changes. Two identical motors driving identical loads will have the same load angle.

Two identical synchronous motors are used but the rotor of one of the motors can be shifted circumferentially with respect to its stator. When both motor rotors are in identical positions relative to their stator winding slotting, the load on the drive will be divided equally between the motors.

While the manufacture of practically identical synchronous motors is not difficult, motor manufacturing tolerances, backlash of the gearing as well as the lineup of the gears makes some form of stator or rotor shift on one of the motors necessary.

The rotor of one of the motors is coupled to the gear input shaft through a collar which is shrunk and keyed to the input shaft. The rotor has a slight clearance fit to the input shaft. The torque of the motor is transmitted through the rotor to the collar by a projecting stub or arm. The position of this stub relative to the collar is adjustable with special set screws held in position with lock nuts. A taper key arrangement takes up the slight clearance and wedges the rotor hub to the input shaft.

Relative rotor position checked

The positions of rotors with respect to their stators can best be determined by electrical measurements with the motors loaded. A mechanical adjustment for very close circumferential alignment of rotors can readily be made by lining up particular points, such as the center damper bar slot, of corresponding rotor poles with a particular point on the corresponding stator teeth. All gear play is taken up in the direction of rotation for both motors before making the rotor shift adjustment.

Factory tests have demonstrated the rotor can be positioned by eye or mechanical measurement for an acceptable electrical load balance at plus or minus five percent of the average load. Further refinement of balance can be done with no load or load tests. These tests are simple and brief. Once positioned, no further adjustment of the rotor is required for many years of service.

No load tests

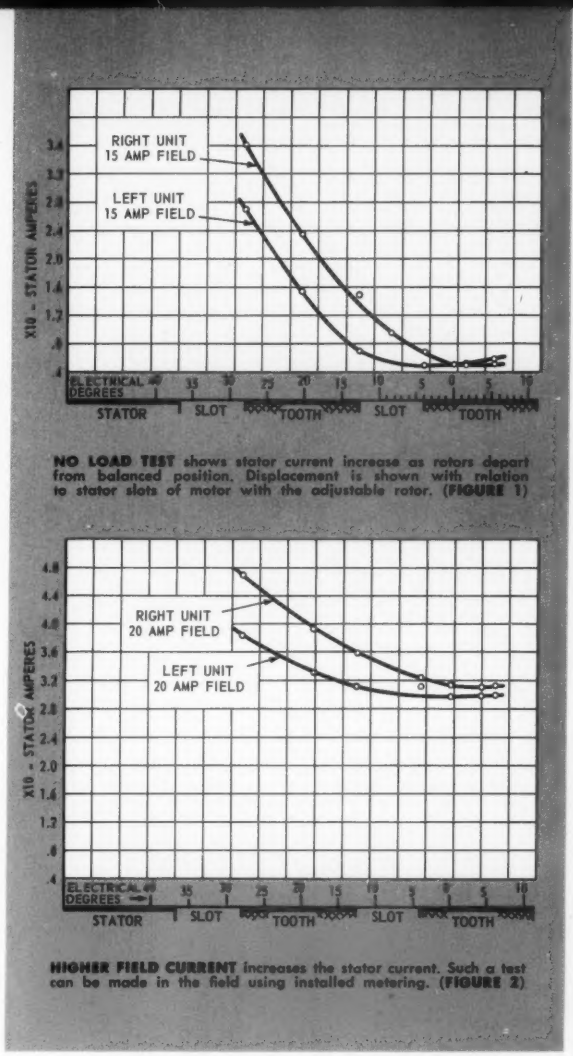
Figure 1 shows the unbalance of stator currents for various positions of mechanical displacement which have been translated into electrical angular displacement. The two synchronous motors are operated under no load with field excitation of both motors identical and set at the no load rated voltage point of the motor saturation curve. This excitation corresponds to minimum stator current for motors operating unloaded.

As the rotor position departs from the "in phase" or identical position in the stator, the current drawn from the supply by each motor differs and a torque is established between them. The data of Figure 1 would be difficult to duplicate in the field since low ratio current transformers are needed to give the balance point at the low stator currents that are characteristic of synchronous motors operating at no load and unity power factor. Figure 2 represents similar data except the motors are excited at a higher value of field current to give higher stator currents at the position for balanced load. This data can be readily obtained in the field before coupling the drive to its load using installed metering.

Tests under load

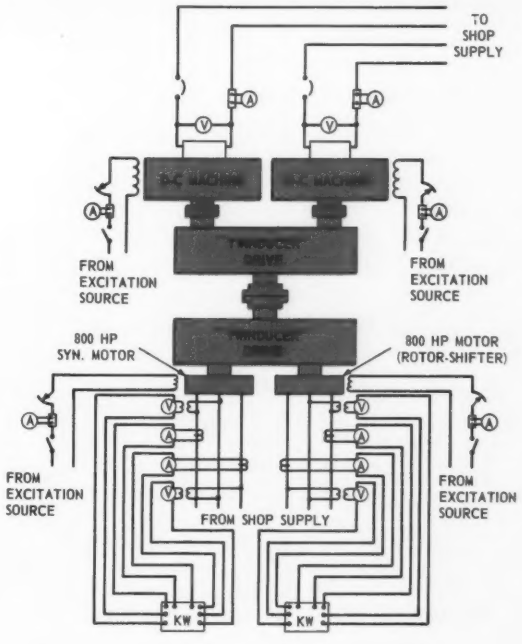
The use of a second drive as a speed increaser made possible the testing of the drive under full load torque operation. The two input shafts of the second drive were coupled to two dc generators which could be loaded in increments to provide any load within the capability of the synchronous motors. Figure 3 is a schematic wiring diagram of the full load test. The ease of rotor positioning for precise load balance at all loads was demonstrated as well as all the characteristics of drive operation under load.

The economy of the new mill drive arrangement using two high speed synchronous motors rather than one large low speed motor has been proved by both test and field experience. The drives are now available in a range of ratings and are expected to solve many space and operating problems in the application of future grinding mills.



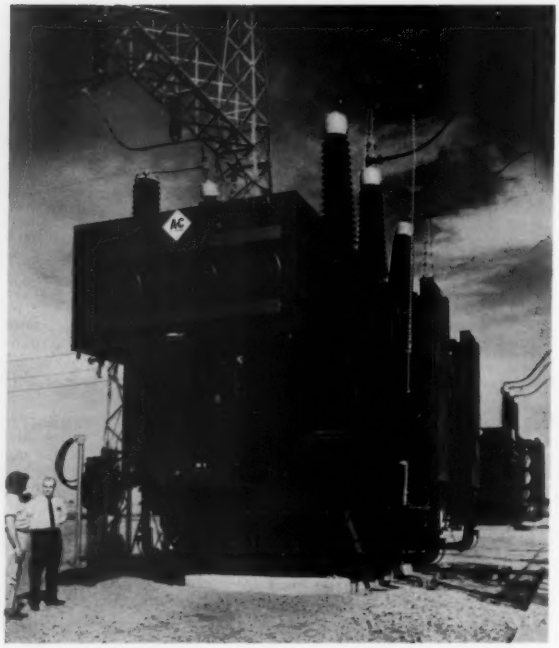
NO LOAD TEST shows stator current increase as rotors depart from balanced position. Displacement is shown with relation to stator slots of motor with the adjustable rotor. (**FIGURE 1**)

HIGHER FIELD CURRENT increases the stator current. Such a test can be made in the field using installed metering. (**FIGURE 2**)



EASE OF ROTOR POSITIONING for load balancing was demonstrated in test setup for finding drive operating data. (**FIGURE 3**)

NEW APPROACH TO LOAD TAP CHANGING



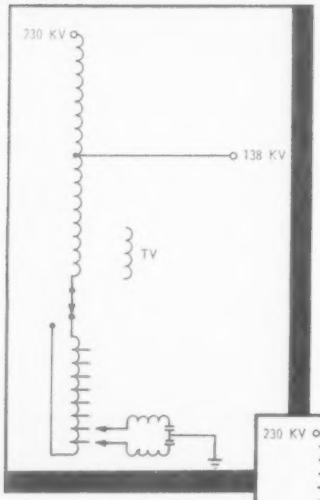
LINE-END TAP CHANGER, mounted on the main tank, simplifies mechanism construction, reduces maintenance, and permits use of standard bushings. Series transformer is eliminated. **(FIGURE 1)**

L. W. SCHOENIG
Transformer Department
Allis-Chalmers Mfg. Co.

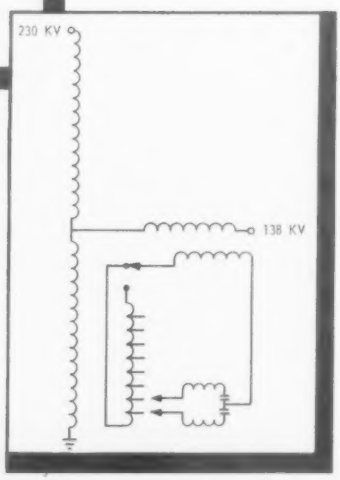
Unique application of load tap changers directly in high voltage circuits reduces transformer size and weight and provides greater efficiency.

SPURRED BY INCREASING POWER system interconnection and the need for better voltage control, autotransformer applications requiring load tap changers are increasing. Autotransformers, such as shown in Figure 1, are getting more attention for these applications.

It has been the practice on some autotransformers with load tap changing equipment to locate the load tap changer in the grounded neutral end of the wye connected low voltage winding as shown in Figure 2. This arrangement permits the use of standard load tap changing mechanisms with an insulation class substantially lower than the normal Basic Insulation Level, BIL, rating of the line end of the low voltage winding. Generally, a 110, 150, or 200-BIL mechanism can be used. If it is



TAP CHANGER can be connected in the neutral of an autotransformer. **(FIGURE 2)**



SERIES TRANSFORMER can be used when regulating the low voltage. **(FIGURE 3)**

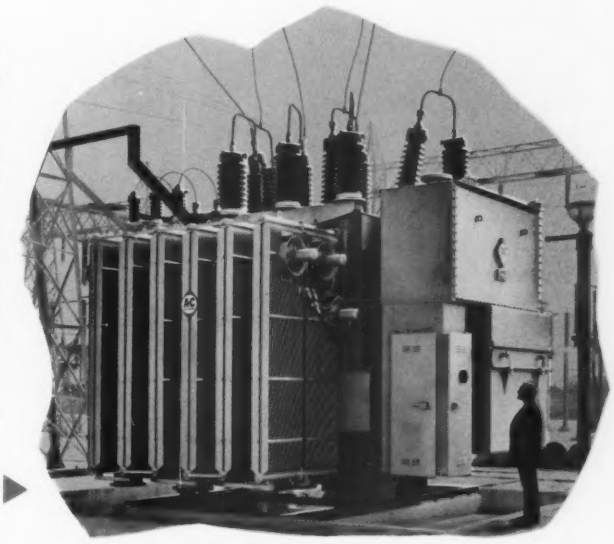
TABLE I

COMPARISON OF LTC LOCATIONS

	Floor Space		Total Weight		Total Losses		Efficiency	
	Sq Ft	% Improvement	Lbs	% Improvement	Kw	% Improvement	%	% Improvement
Auto Transformer with Series Transformer and LTC Equipment	700	—	316,000	—	208	—	99.59	—
Auto Transformer with Line-End LTC Equipment	570	19	246,000	22	166	20	99.67	8

The transformers are rated 50/83 mva, 138/69 — 13.2 kv with ± 10 percent LTC in the 69-kv circuit.

assumed that the low voltage is constant and the high voltage is to be regulated, as is frequently the case with a step-up autotransformer, the load tap changer will subtract or cut out turns to increase the output voltage of the high voltage and add or cut in turns to decrease the output voltage. Since the low voltage is assumed to be constant and the number of turns in the low voltage winding varies with the tap position, the transformer operates with varying volts per turn and the flux density in the core changes. As a result, the core loss varies from a maximum at maximum boost to a minimum at maximum buck. Since the core must be designed for the maximum flux density, a larger and heavier core is re-



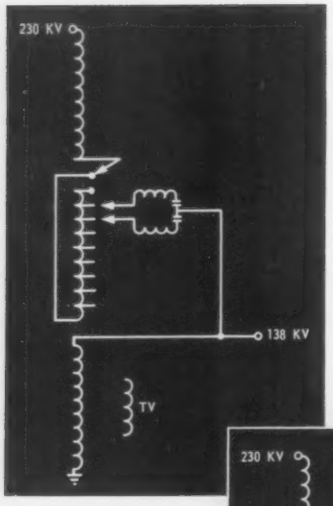
IMPROVEMENT in this 50/83.3-mva, three-phase autotransformer using line-end plus or minus 10 percent tap changer in low voltage circuit is given in Table 1. (**FIGURE 4**)

TABLE II

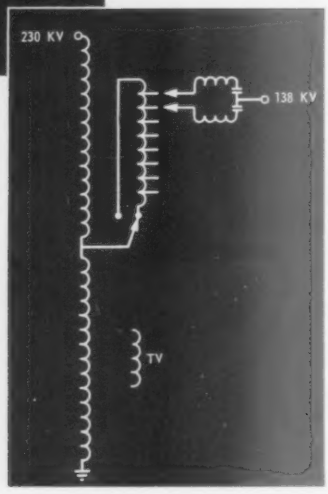
COMPARISON OF LTC LOCATIONS FOR LARGER UNITS

	Line End Tap Changer	LTC in Common Winding	LTC with Series Transformer
Weight			
Core and Coils	240,000	260,000	300,000
Case	80,000	85,000	90,000
Oil	120,000	135,000	165,000
Total	440,000	480,000	555,000
Dimensions			
Height	290	295	295
Length	380	375	415
Width	210	230	215
Impedance			
Neutral	7.0	7.0	7.0
Max .Buck	7.3	9.4	7.2
Max Boost	7.5	6.1	7.1
Losses			
Core			
Neutral Position of LTC	145	155	135
Max Buck Position of LTC	145	125	175
Max Boost Position of LTC	145	195	175
Total Loss			
Neutral Position of LTC	500	490	585
Max Buck Position of LTC	570	565	685
Max Boost Position of LTC	470	470	570
Winding Arrangement	Fig. 3	Fig. 4	Fig. 2

Transformers rated 200 mva, 230/138 — 13.8 kv, 750/450 — 110 BIL, 3 phase, Type FOA autotransformers.



LINE-END tap changer in series winding varies the high voltage in step up unit. **(FIGURE 5)**



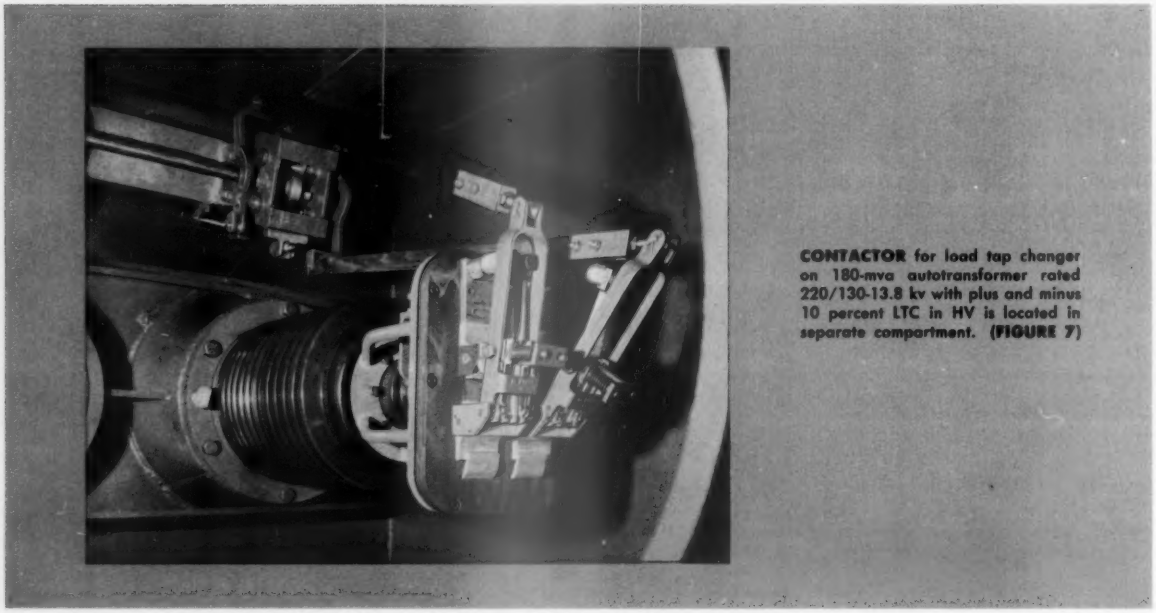
LINE-END tap changer in low voltage circuit varies the low voltage in step down unit. **(FIGURE 6)**

quired, significantly increasing the total weight and dimensions of the transformer.

The variation in volts per turn resulting from the use of a load tap changing mechanism in the grounded neutral of an autotransformer virtually precludes the use of the tertiary as a source of power. The voltage of the tertiary changes with each change in tap position of the load tap changer. A tertiary voltage variation of approximately ± 20 percent is not uncommon. Without maintaining a constant voltage with a separate expensive regulating device, the tertiary cannot be used for station power, local power distribution, or be connected to static capacitors or reactors for power factor correction. However, if the tertiary is used only to provide a path for third harmonic current or for neutral stabilization, the variation in voltage presents no problem.

More frequently, series transformers have been used to isolate autotransformer load tap changers and to permit lower insulation class load tap changers. Since the series transformer is usually excited from the tertiary voltage, the voltage class of the tertiary voltage determines the insulation class of the load tap changing mechanism. Figure 3 shows a winding arrangement of a 230/138-kv load tap changing autotransformer which utilizes a series transformer in its 138 kv circuit.

The use of a series transformer materially increases the overall size and weight, and also increases the core and copper losses of the complete unit. The core and coil assembly of the series transformer used as part of a 150-mva, 230/138-kv ± 10 per cent load tap changing unit is equalient to a 15,000-kva, 138-kv, 3-phase unit. The core and coil of this assembly weighs approximately 45,000 lbs, and increases the core loss about 30 kw at maximum buck or boost and the copper loss about 70 kw at full load.



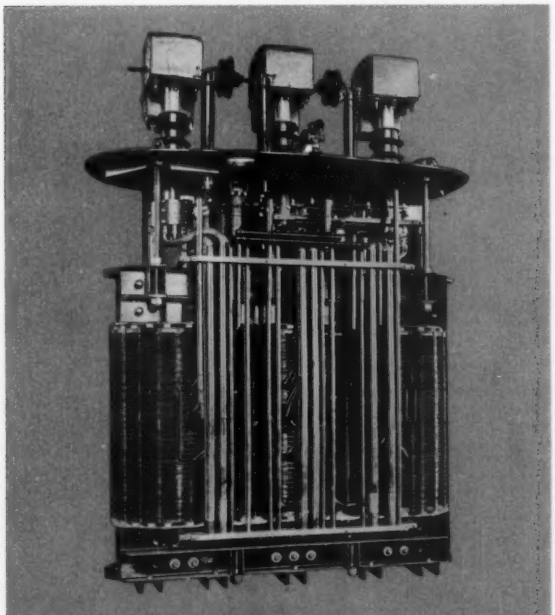
CONTACTOR for load tap changer on 180-mva autotransformer rated 220/130-13.8 kv with plus and minus 10 percent LTC in HV is located in separate compartment. **(FIGURE 7)**

Line-end tap changer simplifies construction

The line-end tap changer is used to eliminate the complications resulting from the use of load tap changing mechanisms in the neutral of autotransformers and to eliminate the need for series transformers. Recently built were two 50/83-mva, 138/69 - 12.5-kv autotransformers with line-end tap changing equipment to control its 69-kv circuit. A comparison of these transformers with duplicate units utilizing series transformers is shown in Table I. The line-end unit is shown in Figure 4.

The effect of LTC location on transformer characteristics is also shown in Table II. A 200-mva, 230/138 - 13.8-kv, three phase autotransformer with ± 10 percent LTC equipment is used as an example.

The circuit diagram of an autotransformer with a line-end tap changer in the series winding is shown in Figure 5. This arrangement is used to vary the high voltage of a step-up autotransformer, or to compensate for incoming high voltage variations of a step-down unit. The line-end tap changer arrangement shown in Figure 6 is used either to vary the low voltage of a step-down unit, or to compensate for low voltage system variations of a step-up unit.



EARLY DESIGNS of line-end tap changers required complicated mechanisms mounted on main transformer bushings. **(FIGURE 8)**

Located in separate compartment

One pole of the new line-end tap changer contactor with its main and arcing contacts, operating mechanism, and barrier bushing support is shown in Figure 7. The breaker portion of the equipment is located in a separate oil filled housing on the end of the transformer and is completely accessible for inspection. The location of the tap changing equipment enables the transformer to be shipped with the load tap changing equipment completely assembled. It is factory aligned, adjusted, and tested, requiring only an inspection at the installation site. Since the load tap changing equipment is not dismantled or removed for shipment, the time required to assemble the transformer for service is substantially reduced.

The dial switch assembly or tap selector switch, as it is sometimes known, is located in the transformer tank. The connections from the tap coils to the dial switch assembly are made in the same manner as for a conventional no load tap changer. Since the dial switch assembly is located adjacent to the tapped coils the leads are short and as a result, the terminal board arrangement is materially simplified.

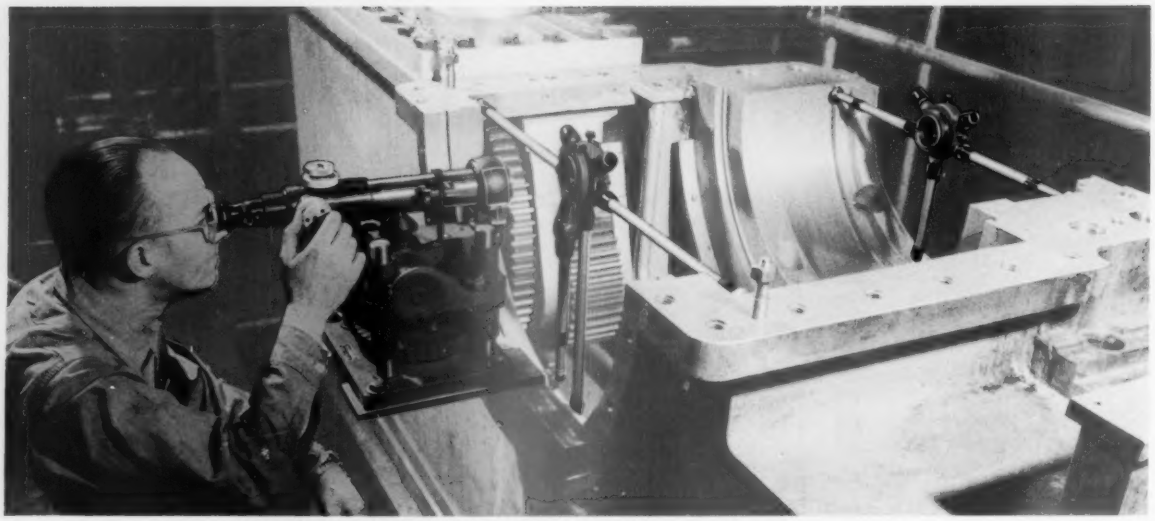
The use of line-end tap changers is not new. A transformer utilizing this winding arrangement with the tap changing equipment bushing mounted was supplied to a large Midwest utility in the late 1920s. The core and coil assembly and tap changer arrangement on this unit are shown in Figure 8. This type of load tap changing equipment was abandoned in favor of conventional load tap changers because of the desire for less complicated equipment.

Modern line-end tap changers eliminate the complex mechanical and electrical arrangements as well as inspection and maintenance difficulties inherent in the bushing mounted tap changer. Since the load tap changing equipment is mounted in an oil filled compartment on the end of the transformer, standard cover bushings can be used.

An installation of two 180-mva, 230/138 - 13.8-kv autotransformers with ± 10 percent line-end tapchangers is shown in Figure 1. These transformers tie two utility systems together to permit an interchange of power. The load tap changing equipment provides the necessary voltage variation for controlled efficient operation.

Where there is a need for an autotransformer with a load tap changer, the new line-end arrangement should be considered for size, weight and operating savings. ◆

HIGH IN NEVADA MOUNTAINS, mining and processing operation provides magnesite refractories for furnace linings in metals industry and chemical magnesium oxide. Gabbs, Nevada plant of Basic, Incorporated, a Cleveland based firm supplies these materials in form of loose dry grains from pea size to powder in bulk or bag. A recent plant expansion included an 8 by 220-ft kiln and an 8 by 80-ft rotary cooler having, at its discharge end, a novel quadrant heat exchanging arrangement for reducing kiln fuel consumption.
Allis-Chalmers Staff Photo by Clarence Hansen



CENTERLINE TELESCOPE is being used in precision alignment of bearing pedestals.

FIELD INSTALLATION TECHNIQUES FOR TURBINE-GENERATORS

W. A. BISHOP
Service Department
Allis-Chalmers Mfg. Co.

Greater precision plus savings in time and expense attained by new techniques in installing large steam turbine-generator units.

ESTABLISHING IDEAL factory assembly and test conditions by extensive new facilities, plus use of optical measuring, has revolutionized installation of steam turbine-generator units. Although greater precision is the crux of the change, it has resulted in reduction of field installation time by one-third.

Turbine-generator units were formerly set on their foundations by driving steel wedges under the soleplates to bring the unit to the proper elevation and slope. This method often oversupported a lightly loaded area and left the heavily loaded areas insufficiently supported. After several years of operation, the deflection and creep of various components could cause misalignment and damage to the turbine.

As turbines increased in size and complexity, the use of wedges evolved into setting subsole plates into grout and shimming the subsole plates to a level plane using a straight edge and machinist's level. After the establishment of the level plane, the lower half of the low pressure turbine cylinder and the bearing pedestals were placed on the bedplates on the shimmed subsole plates and the lower halves of the high pressure and intermediate pressure cylinders were also set in place. Alignment consisted of putting in the spindles, checking the side clearances with thickness gage readings on all blade seals, and assembling the turbine upper halves complete with lead wires in the top and bottom of the blade seals to check the clearances. Since the internal clearances on the blade rings and seals were set in the shop with load blocks and dowel pins, these clearances could be maintained in the field upon reassembly.

The turbine was then disassembled and the spindles were removed to check the imprints on the bottom lead wires. Any changes necessary to obtain proper internal clearances were made and the turbine was completely reassembled. Next the shafts were checked for alignment by measuring the parallelism and concentricity of the coupling shafts.

Temporary alignment keys between the different cylinders and between the spindle-cylinder sub-assemblies and the bearing pedestals were used in shop erection. The field assembly coincided with the shop setting, but because of temperature changes and differences in locations

for taking readings, and because parts were free to slide, settings had to be checked, corrected and rechecked until alignment was obtained.

New methods developed

A major part of this procedure has been changed with the advent of optical tooling. The chief advantage of optics over previously used methods is that a line of sight, being weightless, does not sag, as does a straight edge or a stretched wire. Measurements can be made from a line of sight with precision. While a line of sight can be diffracted by heat waves, the optical tools provide a fast and accurate means of alignment for large pieces in stable thermal conditions.

The accuracy of the precision sight level, an optical tool of major importance, is obtained by using a coincidence bubble. The telescope is pivoted about a horizontal axis by means of a half-ball and socket, which intersects the vertical axis of the instrument. The four-screw leveling prevents the instrument from changing height when the leveling screws are turned. A tilting wheel under the eyepiece is turned to pivot the telescope. Since the height of the telescope axis is fixed, and does not change when the telescope is leveled, the horizontal plane swept by the leveled line of sight is always the same distance above the ground.

The instrument is set up with an optical micrometer which reads the vertical displacement in .001-inch increments, and is adjusted to its reversing point on the horizontal pivot. The reversing point is the point at which the telescope can be rotated around its pivot and remain in the same horizontal plane, without further adjustment. This arrangement simplifies taking readings, so that it is necessary only to rotate the telescope, focus, and take the readings. The height of the instrument is set so that the line of sight is several inches above the plane of the area to be checked, and an optical tooling scale is held by means of a magnet to the various points at which the readings are being taken. The elevation of the instrument is immaterial, being on a fixed plane, and the differences in the elevations of the points being read are obtained from the differences in the readings.

With a precision sight level, the subsole plates which are set to elevation within 1/16 inch maximum deviation can be shimmed to a level plane more rapidly and more accurately than with previous methods.* Permanent shim packs are prepared at the factory for each subsole plate to compensate for deviations of the components because of machining tolerances and to establish desired slope variations from a level reference plane. These shim packs are placed at their respective locations over the level plane established in the field. The bedplates can then be set so that the horizontal turbine joints will coincide with the elevations and slopes of the horizontal joints measured at the factory.

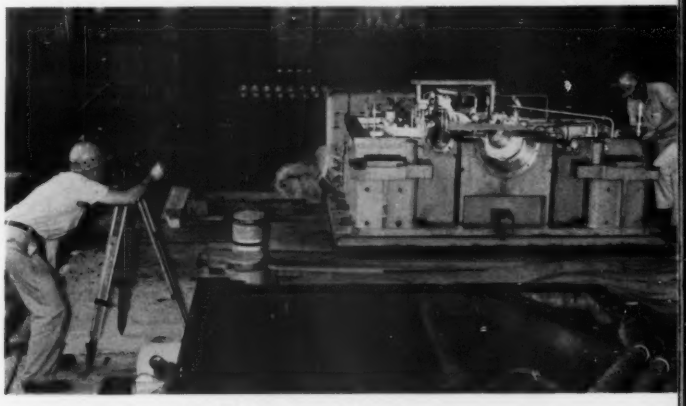
The low pressure turbine casing and the lower halves of the bearing pedestals are then placed on the preset bedplates, and the lower halves of the high pressure and intermediate pressure turbine cylinders are set on their supports. With the lower halves of the cylinders and bearing pedestals in place the horizontal parting joints are checked for correct setting. This is done to be sure that the horizontal parting joints of the components are level within themselves and at the proper slope relative to the slope of the spindle centerline. The horizontal joint of the bearing pedestals must also conform to the spindle slope at the journal bearing area because the thrust bearing, main oil pump, governor, and several supervisory instruments are set in the pedestals in conformity with the slope of the spindle shaft.

Formerly these levels and slopes were checked by using a machinist's level and a long straight edge on the parting joints. In addition to being slow and tedious, this method was only fairly accurate. By using a precision sight level, mounted on a rigid stand placed midway in the area to be checked and six feet from the closest readings, the elevation of the horizontal joints can be checked within minutes after the initial setup of the instrument.

Centerline telescope also used

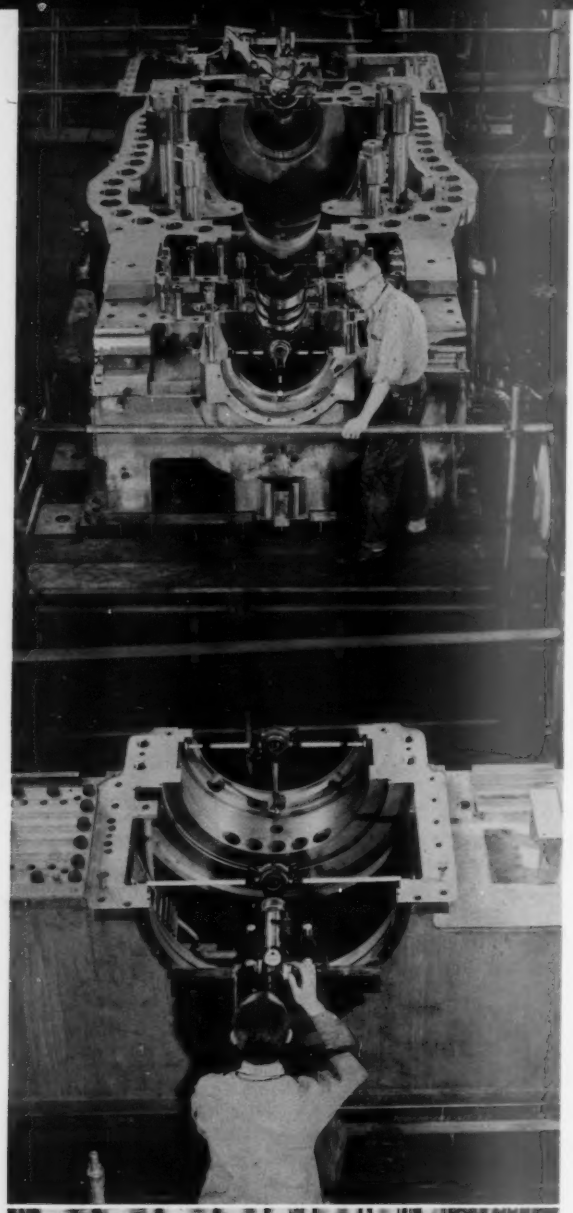
The centerline telescope is a precision optical tool that is also used to establish lines of sight relative to a given reference point. The instrument is basically a telescope barrel with built-in horizontal and vertical optical micrometers which read plus or minus .050-inch displacement; are calibrated to read directly in .001-inch increments. The telescope is clamped to a mounting table, which could be compared with an engine lathe compound. The base of the mounting table is rigidly clamped down and the telescope can be adjusted horizontally, vertically, and angularly.

The targets, either a circular glass with a paired line pattern, or an open circular ring with crosshairs, are set in an adjustable target holder. The target holder is supported by three telescope legs, and its position is adjusted by means of a dial indicator which pivots on a bearing around the target holder bore. By indicating the machined bore where the target is set up with respect to the target holder bore, the target can be set with respect to the center of the machined bore.



HORIZONTAL PARTING JOINT of No. 1 control pedestal is shown being checked with precision level.

* "Setting Sub-Sole Plates," S. L. Soloff and G. A. Ronkanen, *Allis-Chalmers Electrical Review*, 2nd Quarter, 1961.



PEDESTAL LINEUP of high and intermediate pressure turbines is shown being made in the shop. Below, sighting a turbine from the low pressure end at the jobsite.

The centerline telescope can be used to check the alignment of major pieces when the lower halves of the low pressure cylinder and the bearing pedestals are set on their bedplates. The bottom halves of the high pressure and intermediate pressure turbines can be set on their supports and checked at the same time or they can be installed later and positioned in alignment by installing the shop fit keys.

If everything is found to be correct, the spindles can be installed with confidence and when the remainder of the turbine sub-assemblies are complete, the alignment of the spindles will also be satisfactory. As the sight level gives the exact elevations, the reading of the centerline telescope is useful mainly in checking the transverse alignment. The final proof of the setting is established with the spindle-to-cylinder micrometer readings and the coupling alignment check.

This method is applicable only for duplication of factory settings. The actual values used for these relative positions of the bearing bores are duplications of the values obtained from the results of the factory alignment. By duplicating these shop readings, the partially erected machine can be checked for correct alignment in the field without costly, time-consuming procedures. If any changes are required, they can usually be made by shifting the unassembled bearing pedestals.

These changes and checks are very quickly and easily performed at this stage of erection compared to the identical moves after all major sub-assemblies are set and bolted together. This procedure saves time and construction costs.

Alignment keying factory fitted

Another new procedure of building turbines is the fitting and machining of alignment keys at the factory. Alignment keys were previously fitted on a temporary basis in the shop and later keys were machined in a local machine shop as the erection progressed. With rigid modern test pits and proper alignment in the shops, it was found feasible to machine the majority of alignment keys for shop test, and later use them in field erection by duplicating shop alignment. Keys thus machined in the shop include those between the low pressure cylinder and the bedplate, between the bearing pedestals and bedplates, between cylinders, and between cylinders and pedestals. In addition to these keys, the load blocks, dowels, and axial keys which align the blade rings to the cylinders are machined in the shop. This procedure simplifies the work because once the bedplates have been positioned, the low pressure components and bearing pedestals can be set directly on their keys and bedplates, eliminating the tedious job of sliding these pieces around on the bedplates to line them up. Any refinements necessary in the alignment of these components can be made by moving component and bedplates together as single pieces. The high pressure cylinder can be set on its supports and the lateral and axial keys can be installed to position the cylinder in the proper relationship to its adjoining parts. Micrometer readings will define the

proper axial relationship between cylinders and pedestals. On a recently erected unit, pin gages were made and used to measure the axial distances. These gages replaced the micrometers and because they had the same coefficient of expansion as the turbine, they eliminated the chance of error in reading micrometers.

The procedure used for measuring the distances between the bedplates is called tramming although the distances are measured with a steel tape instead of a set of trammels. Scale measures are taken axially, transversely, and diagonally between bedplates. This set of measurements places the bedplates close enough so that a minimum of movement is needed during alignment and erection.

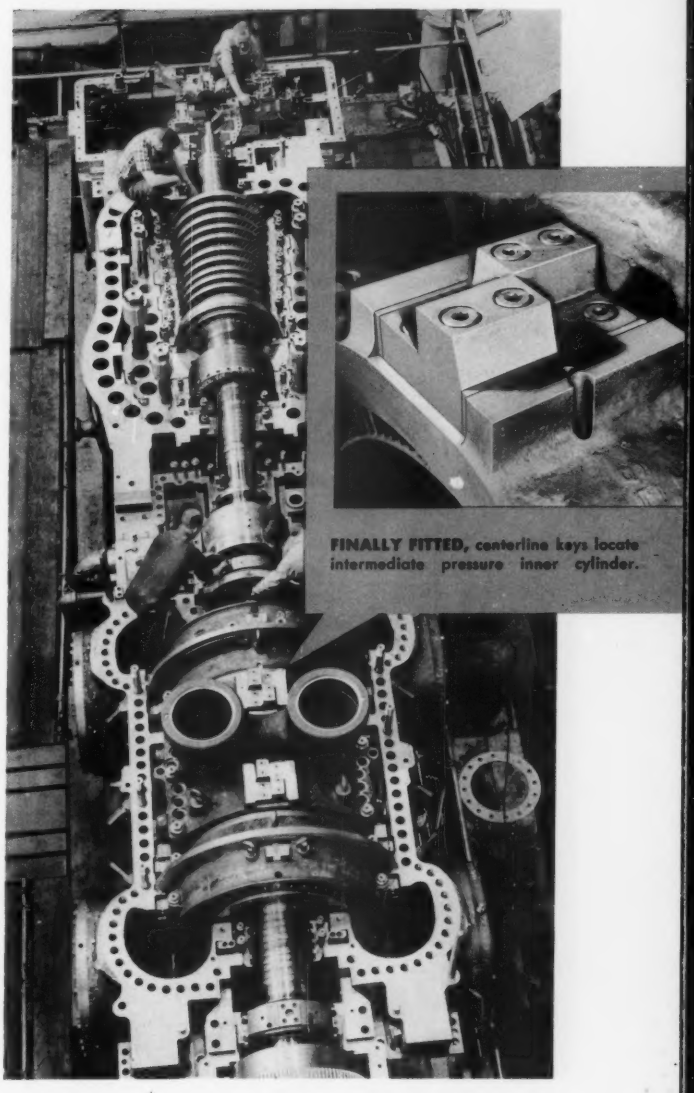
Another new and very important procedure is the weighing of the support feet of major components. An even distribution of weight over the designed load areas is thus assured. Also the component is free of twist or unnatural deflections. This weighing is accomplished by moving shims from side to side across the unit, distributing the weight correctly, without changing the alignment of the component. The resulting movement is only a slight rotation around the longitudinal centerline axis. This procedure decreases internal strains, vibrations, and tendency to settle unevenly.

Larger assemblies installed

With these new developments and advancing techniques, it will be possible to build future turbine-generator units with a selection of various methods and procedures. It is not feasible to use every method on each unit as such a procedure would result in extraneous and redundant operations. One method or a combination of methods can be adapted for a particular unit to enable the field erection to proceed in the most efficient and economical manner for that specific job. In this way, the several major components can be assembled at the same time, with the added assurance of a secondary precision check during the progress of the job. If this secondary check can be done quickly and with accuracy, and is independent of other methods, it will assure correct assembly all the way through the job.

A recent example of these advanced methods is the successful use of optical tooling on the installation of a tandem compound double-flow unit. A factory-built high pressure spindle-cylinder sub-assembly was set as a package directly in its place in the field.

The lower half of the low pressure cylinder and the lower half of the No. 1 bearing pedestal were set on their bedplates. They were then aligned using the centerline telescope and the horizontal joints were checked for elevation by using the sight level. The high pressure turbine, which was shipped as a complete shop assembly, was set directly into place between them. Since it was supported on its centerline and keyed to both the low pressure cylinder and the bearing pedestal, which were correctly positioned by optical instruments, it was in the correct alignment when the shop-fitted alignment keys were installed.



FINALLY FITTED, centerline keys locate intermediate pressure inner cylinder.

Using this erection procedure, the piping was fitted to the high pressure turbine after its placement. Meanwhile the remainder of the unit was being assembled, and the speed of the whole process of erection was correspondingly increased. When the remainder of the turbine sub-assemblies were completed, the spindle couplings were checked for alignment and were found satisfactory.

On units where the installation can be performed in such parallel operations without interference or dependence on other operations, an appreciable saving of field installation time is possible as compared with the older series method of construction.

These revolutionary improvements brought about through coordinated planning and purpose have raised steam turbine-generator unit installation to a new plateau of precision. Many stubborn problems formerly related to installation of this major equipment no longer exist and the way is paved for the astonishing progress on all fronts that power enterprises are now experiencing. ◆

SYMMETRICAL COMPONENTS SOLVE UNUSUAL CIRCUIT PROBLEMS

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Switchgear Department
Allis-Chalmers Mfg. Co.

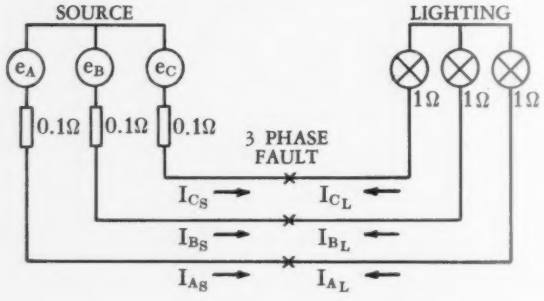
While symmetrical components are generally recognized as a valuable tool in common fault and stability analysis, they can also be helpful in solving certain specialized power system problems.

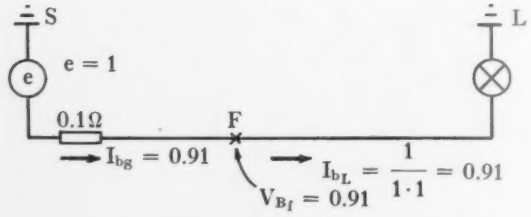
There are certain problems on power and distribution systems that can be solved more easily by using symmetrical components. Examples give solutions to such circuit problems.

To orientate the symmetrical component relation, a simple circuit fault calculation brings out two basic points that should be recognized:

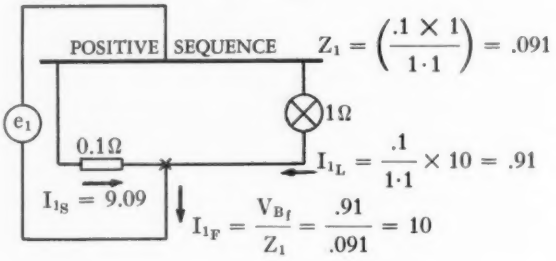
1. The before fault current and voltage allows all loads, even lighting circuits, to be considered as a source.
2. The direction of the resultant fault current is shown flowing toward the fault point. All currents flowing toward the fault point are considered plus, and those away minus.

3 PHASE SHORT CIRCUIT BETWEEN SOURCE AND STATIC LOAD





BEFORE FAULT


POSITIVE SEQUENCE
$Z_1 = \left(\frac{.1 \times 1}{1 \cdot 1}\right) = .091$
e_1
1Ω
0.1Ω
$I_{1_L} = \frac{.1}{1 \cdot 1} \times 10 = .91$
$I_{1_S} = 9.09$
$I_{1_F} = \frac{V_{B_f}}{Z_1} = \frac{.91}{.091} = 10$

DURING FAULT

$$S\begin{cases} I_{A_S} = [(I_{1_S} + I_{b_S}) + I_{2_S} + I_{0_S}] \\ \quad = [(9.09 + .91) + 0 + 0] = 10.0\,|\underline{0°} \\ I_{B_S} = [a^2(I_{1_S} + I_{b_S}) + aI_{2_S} + I_{0_S}] \\ \quad = [a^2(9.09 + .91) + 0 + 0] = 10.0\,|\underline{-120°} \\ I_{C_S} = [a(I_{1_S} + I_{b_S}) + a^2I_{2_S} + I_{0_S}] \\ \quad = [a(9.09 + .91) + 0 + 0] = 10.0\,|\underline{120°} \end{cases}$$

$$L\begin{cases} I_{A_L} = [(I_{1_L} + I_{b_L}) + I_{2_L} + I_{0_L}] \\ \quad = [(.91 - .91) + 0 + 0] = 0 \\ I_{B_L} = [a^2(I_{1_L} + I_{b_L}) + aI_{2_L} + I_{0_L}] \\ \quad = [a^2(.91 - .91) + 0 + 0] = 0 \\ I_{C_L} = [a(I_{1_L} + I_{b_L}) + a^2I_{2_L} + I_{0_L}] \\ \quad = [a(.91 - .91) + 0 + 0] = 0 \end{cases}$$

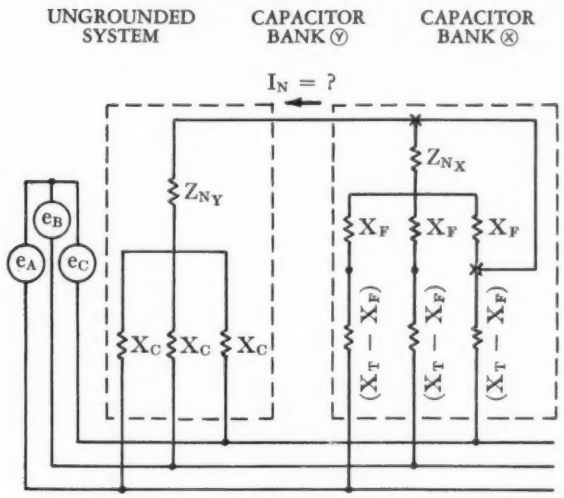
$$F\begin{cases} I_{A_F} = [I_{1_F} + I_{2_F} + I_{0_F}] = [10 + 0 + 0] \\ \quad = 10\,|\underline{0°} \\ I_{B_F} = [a^2I_{1_F} + aI_{2_F} + I_{0_F}] = [a^2(10) + 0 + 0] \\ \quad = 10\,|\underline{-120°} \\ I_{C_F} = [aI_{1_F} + a^2I_{2_F} + I_{0_F}] = [a(10) + 0 + 0] \\ \quad = 10\,|\underline{120°} \end{cases}$$

Less common problem solved

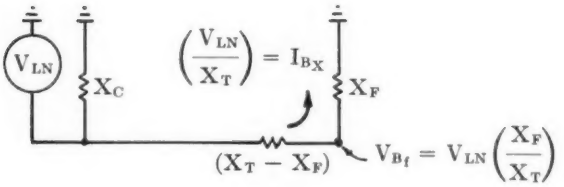
Neutral currents flowing between parallel capacitor banks during an internal fault to ground in one of the capacitor banks can be obtained by using symmetrical components. Conventional loop equations used to derive a relation for the neutral currents would require considerable more effort.

By first constructing the symmetrical component diagram, the equations for neutral current can be simply and

NEUTRAL CURRENTS IN PARALLEL CAPACITOR BANKS



2-PARALLEL CAPACITOR BANKS ON AN INFINITE SYSTEM



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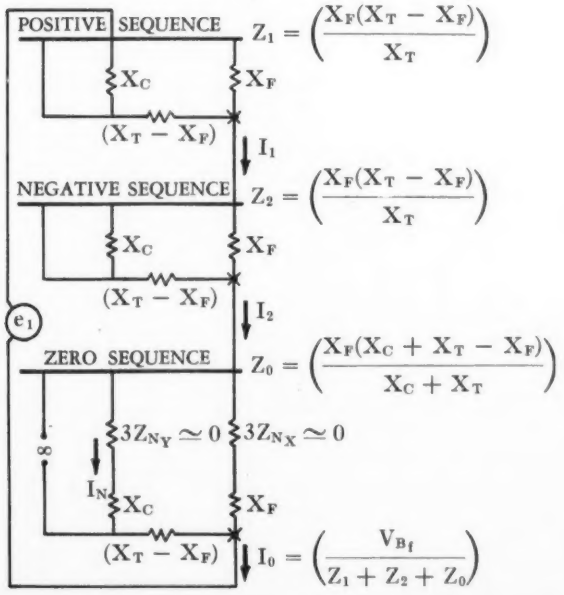


directly developed by inspection. The equations are expressed in general terms. They are valid for unequal capacitor banks as well as equal banks.

Equation No. 2 represents the neutral current in terms of the normal phase current.

$$I_N = \left\{3V_{LN}\left(\frac{X_F}{X_T}\right)\left(\frac{X_F}{X_C + X_T}\right) \Big/ \left[\left(\frac{2X_F(X_T - X_F)}{X_T}\right) + \frac{X_F(X_C + X_T - X_F)}{(X_C + X_T)}\right]\right\}$$

$$I_N = \{3V_{LN}X_F/[2(X_T - X_F)(X_C + X_T) + X_T(X_C + X_T - X_F)]\}$$

$$I_N = \{3V_{LN}X_F/[3X_T(X_C + X_T - X_F) - 2X_FX_C]\}$$

$$\boxed{I_N = \left\{V_{LN} \Big/ \left[X_T\left(\frac{X_C + X_T}{X_F} - 1\right) - \frac{2}{3}X_C\right]\right\}} \quad \text{Eq. 1}$$

Equation 1 represent the neutral current in terms of line to neutral voltage and capacitor reactances. Since the normal phase current of the faulted capacitor bank is equal to the line to neutral voltage divided by the capacitor bank reactance (X_T), equation 1 can be rewritten in terms of normal phase current, as shown in equation 2.

$$\boxed{I_N = \left(\frac{1}{\frac{X_C + X_T}{X_F} - \frac{2}{3}\frac{X_C}{X_T} - 1}\right) I_{B_X}} \quad \text{Eq. 2}$$

From equation No. 2 the neutral current can be expressed in terms of the number of capacitor groups in series by simple ratio proportion.

When the capacitor banks are equal, equation No. 2 in terms of the number of groups could be represented by direct substitution as follows:

$$I_N = \left(\frac{1}{\frac{M + M}{N/M} - \frac{2}{3}\frac{M}{M} - 1}\right) I_{B_X}$$

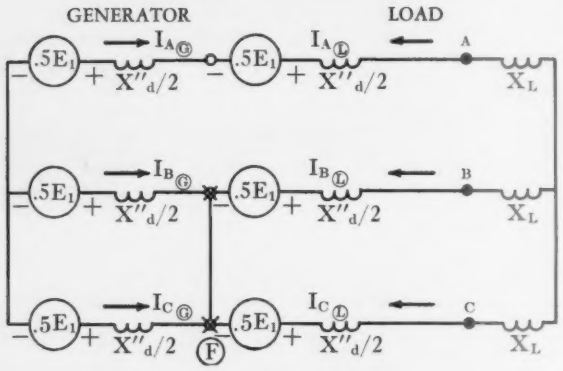
$$I_N = \left(\frac{1}{\frac{2M^2}{N} - \frac{5}{3}}\right) I_{B_X} = \left(\frac{3N}{6M^2 - 5N}\right) I_{B_X}$$

where M = groups in series
N = number of faulty groups in series
I_{B_X} = normal phase current

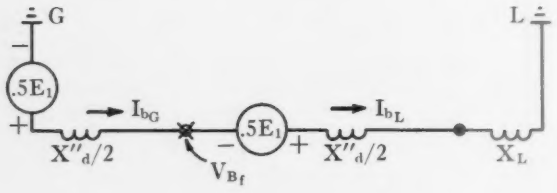
Generator circuit problem solved

The example of an internal fault in a generator shows the use of symmetrical components in conjunction with basic loop equations as a simple means of solving circuit problems.

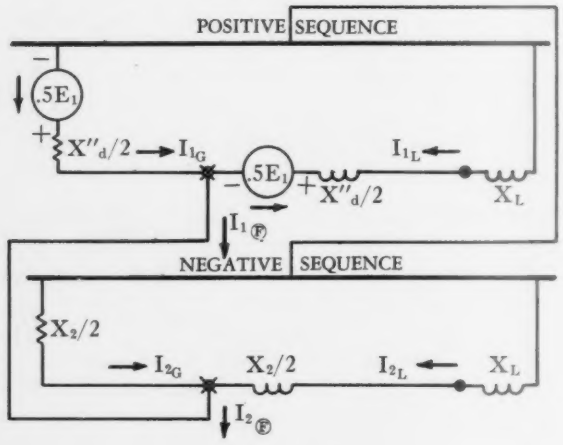
UNBALANCE INTERNAL FAULT IN A GENERATOR



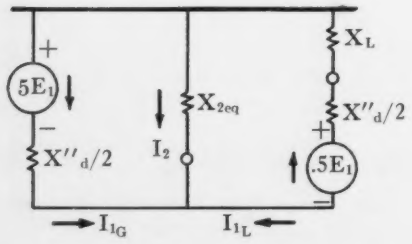
GENERATOR FAULTED MIDWAY BETWEEN B & C PHASES



BEFORE FAULT



DURING FAULT



DURING FAULT EQUIVALENT

LOOP EQUATIONS OF EQUIVALENT CIRCUIT

$$.5E_1 - I_{1_G}\frac{X''_d}{2} + I_2X_{2eq} = 0 \qquad \text{Eq. 1}$$

$$.5E_1 + I_{1_L}\left(\frac{X''_d}{2} + X_L\right) - I_2X_{2eq} = 0 \qquad \text{Eq. 2}$$

$$I_{1_L} = -(I_2 + I_{1_G}) \qquad \text{Eq. 3}$$

Substituting Eq. 3 into Eq. 2

$$.5E_1 - I_{1_G}\left(\frac{X''_d}{2} + X_L\right) - I_2\left(\frac{X''_d}{2} + X_L + X_{2eq}\right) = 0 \qquad \text{Eq. 4}$$

Eq. 1 and Eq. 4 can be solved simultaneously

$$A_1 = \left(\frac{X''_d}{2}\right)$$

$$A_2 = (X_{2eq})$$

$$B_1 = \left(\frac{X''_d}{2} + X_L\right)$$

$$B_2 = \left(\frac{X''_d}{2} + X_L + X_{2eq}\right)$$

$$A_1I_{1_G} - A_2I_2 = .5E_1 \qquad \text{Eq. 1'}$$

$$B_1I_{1_G} + B_2I_2 = .5E_1 \qquad \text{Eq. 4'}$$

multiplying Eq. 1′ by (B_2/A_2) and adding to eq. 4′ yields Eq. 5.

$$I_{1_G} = \left[.5\left(\frac{B_2}{A_2} + 1\right)E_1 \Big/ \left(\frac{B_2}{A_2}A_1 + B_1\right)\right] \qquad \text{Eq. 5}$$

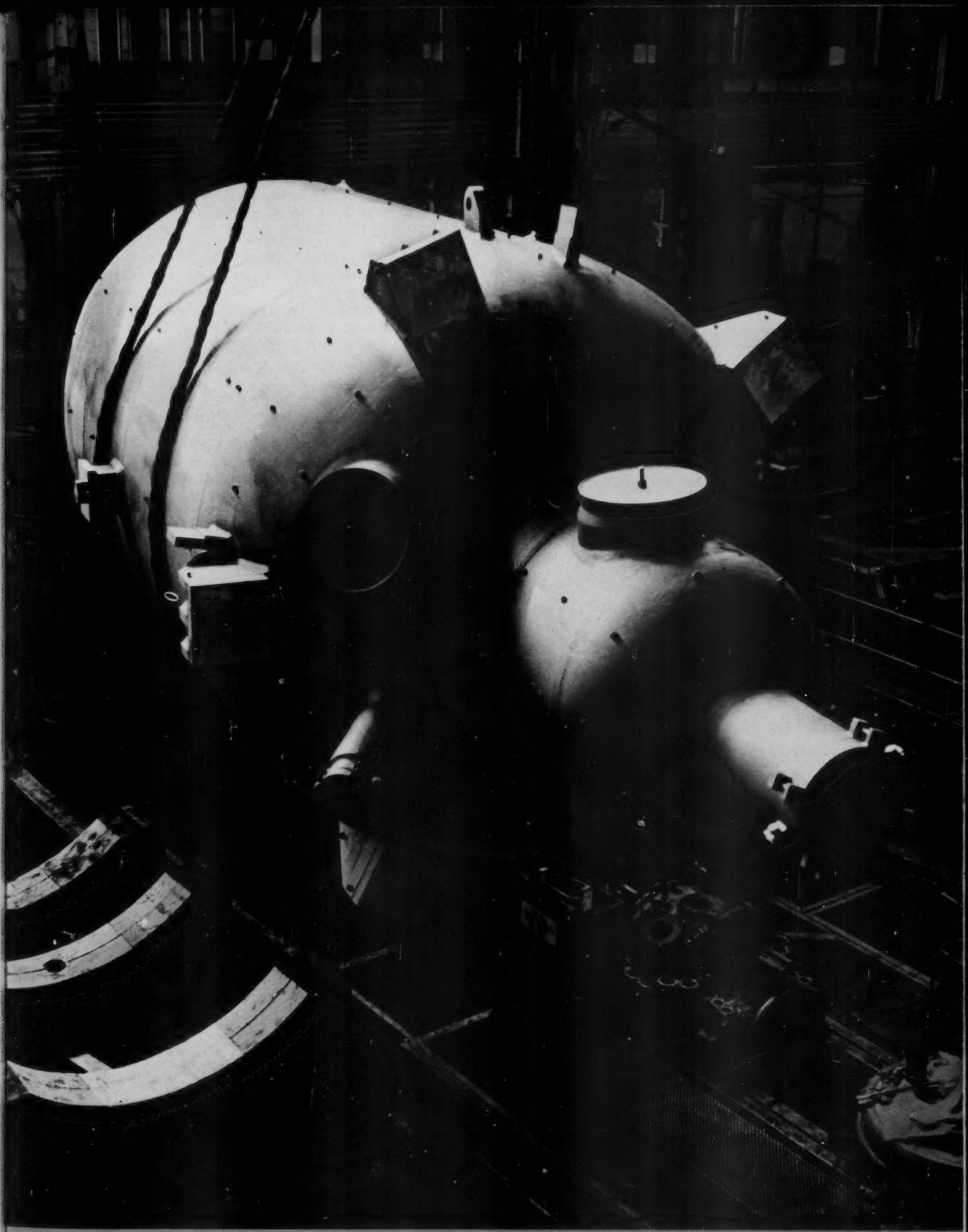
then Eq. 1′ can be solved for I_2 in terms of I_{1_G}, yielding Eq. 6.

$$I_2 = [(I_{1_G}A_1 - .5E_1)/A_2] \qquad \text{Eq. 6}$$

The following should be noted in this example:

1. The symmetrical component analysis must be used in analyzing unbalanced rotating machinery circuits because the machine reactances to positive, negative, and zero sequence current are not equal, so applying loop equations directly using subtransient reactance would not be a valid approach.
2. The location of the fault, midway in the winding between B and C phase necessitates the use of loop equations to solve for the symmetrical component fault currents. The usual equation.
   $$I_1 = I_2 = [E_1/(Z_1 + Z_2)],$$
   cannot be directly applied.

To approach certain unusual problems with a simple basic understanding of symmetrical components will enable you to find solutions with little difficulty and without using involved methods. ◆



STARTUP IN MID-1962 is schedule for Pathfinder Atomic Power Plant in Sioux Falls, S. D. The 66-ton reactor pressure vessel, now installed, is shown being loaded at West Allis. The 36-ft high vessel, viewed from the bottom, will house a 200-mw (thermal) reactor core with integral nuclear superheater. The plant's 66-mw turbine-generator has its horizontal centerline below the operating floor level for maximum radioactive shielding. Turbine will operate on 540 psi, 825 F superheated steam from the 18-in. diameter pipe at the vessel bottom. Pumps recirculate 600-psi, 486 F water at 60,000 gpm through the reactor. The recirculated water enters the reactor through three inlets in the four-ft diameter plenum and returns to the pumps through three outlets near the bottom of the vessel.

DETERMINING FURNACE TRANSFORMER LOSSES

C. T. BRADBURN
Transformer Department
Allis-Chalmers Mfg. Co.

Overall furnace efficiency is frequently required in the application of arc furnaces. Transformer losses are needed for these calculations. Here are the basic formulas.

FURNACE TRANSFORMER TAP changes are made in the high voltage winding because currents in the secondary windings are too high to make tap changing in these windings practical. The transformer primary volts per turn, V/T, is changed to vary the low voltage as shown in Figure 1. The actual nameplate, or specified low voltage values may, therefore, be used as a basis for comparison and for determining the factors affecting the losses.

Maximum low voltage, LV at position Z, is obtained with the minimum number of turns in the high voltage winding. At this position the volts per turn is maximum. To obtain LV at position Y, or minimum LV, maximum turns in the high voltage winding are utilized. Maximum core excitation occurs at position Z with reduced excitation at other tap positions. Core loss, is proportional to excitation.

Position X is the specified minimum low voltage, LV_2, at which full kva capacity can be obtained. At low voltages below this point, reduced kva proportional to the low voltage is obtained. Current in the high voltage winding, under this condition, will be reduced and proportional to the output kva. Low voltage current will be equal to the current at the minimum full capacity low voltage, LV_2. Figure 2 shows the relationship between the several factors affecting the losses of a furnace transformer and the low voltage values.

The physical parts of the furnace transformer, such as core iron, windings, and tank, are larger than the rated nameplate kva would indicate because of the extended high voltage winding. The kva rating corresponding to the physical parts is referred to as the equivalent comparative kva, kva_2. This rating is used as a basis for loss evaluation or other comparisons and may be calculated as follows:

$$kva_2 = N \times P \times kva \qquad \text{Eq. 1}$$

Figure 3 provides values for N and P for various ratios of specified low voltages.

Determining core and copper losses

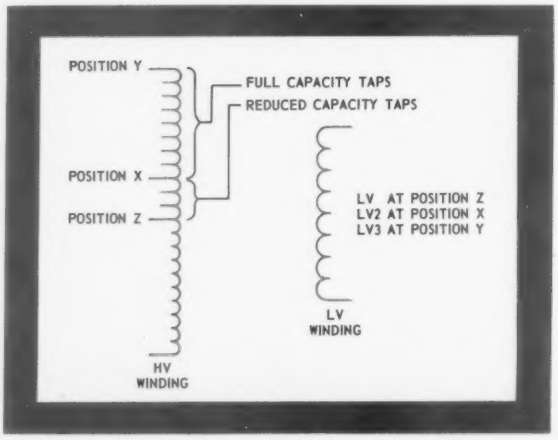
Maximum core loss, F, and copper loss, C, on an equivalent transformer of kva_2 capacity may be calculated from the test report. Furnace transformer losses are usually tested and guaranteed at a low voltage equal to LV_2. The core loss at this point can be considered as being F_1 and the total copper loss as being CT_1, if LV_2 is made the considered low voltage LV_1. However, the maximum loss values occur at LV for core loss and LV_2 for copper loss. Assuming actual losses are taken from a test report at LV_2, and making $LV_1 = LV_2$; maximum core loss F can be obtained from Eq. 11 which is written

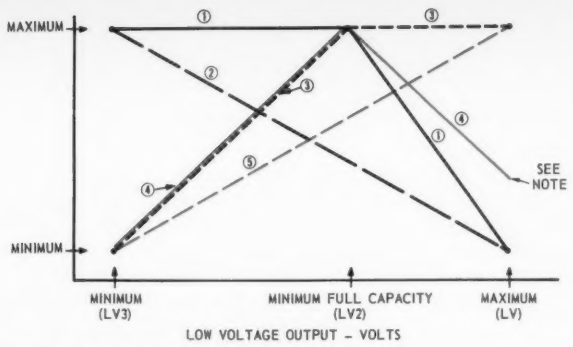
$$F = F_1 \times \frac{LV}{LV_2 \times M} \qquad \text{Eq. 2}$$

and total copper loss C may be obtained from Eq. 22 which may be written

$$C = \frac{2 \times CT_1}{\frac{LV_3}{LV_2} + 1} \qquad \text{Eq. 3}$$

PRIMARY VOLTS PER TURN varied to change secondary voltage. **(FIGURE 1)**





① ——— Low voltage current and low voltage copper loss (CL1)
② — — Amount of high voltage winding used.
③ - - - High voltage current and output KVA (KVA1)
④ ——— High voltage copper loss (CH1) and total loss (T1)
⑤ — — — Core loss (F1)

NOTE: Normal condition will have this point less than maximum (at LV2) but more than minimum (at LV3). Changes in relative values of LV2 and LV could change this relation. LV2 is always associated with maximum copper losses.

RELATION of factors that determine losses are given. **(FIGURE 2)**

If actual losses on a furnace transformer are taken from tested low voltage values other than LV_2, then LV_1 is set equal to the particular low voltage at which the tested values are taken and Eq. 2 is written for maximum iron loss

$$F = F_1 \times \frac{LV}{LV_1 \times M} \qquad \text{Eq. 4}$$

and Eq. 3 for the maximum copper loss as

$$C = \frac{2 \times CT_1}{\left[\frac{LV_3}{LV_2} \times \left(\frac{LV_1}{LV_2}\right)^2 + \left(\frac{LV_2}{LV_1}\right)^2\right]} \qquad \text{Eq. 5}$$

If only iron loss F_1 and total loss T_1 are given on the test report for some low voltage LV_1, then CT_1 is determined from Eq. 21 which can be written

$$CT_1 = T_1 - F_1 \qquad \text{Eq. 6}$$

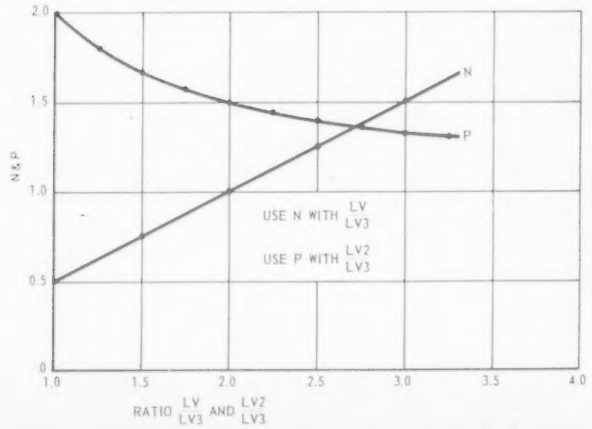
If actual losses are not available from a test report, the maximum core loss, F, and maximum copper loss, C, on the required kva_2 capacity basis for representative modern furnace transformers may be assumed to be as follows:

For a 3 phase unit

$$F = 11.5 + \left(\frac{kva_2 \times 1.08}{1000}\right) \qquad \text{Eq. 7}$$

For a 1 phase unit

$$F = 9.8 + \left(\frac{kva_2 \times .915}{1000}\right) \qquad \text{Eq. 8}$$



VALUES for N and P used in loss evaluation. **(FIGURE 3)**

SYMBOLS

HV	High voltage in volts[1]
LV	Maximum low voltage in volts
LV_1	Low voltage at any considered voltage (high voltage tap) in volts
LV_2	Lowest full capacity (rated kva low voltage) in volts
LV_3	Minimum low voltage in volts
kva	Rated (nameplate) kva at 55 C average copper rise[2]
kva_1	Rated kva capacity of transformer at LV_1
kva_2	Equivalent comparative kva
F	Maximum core loss on a kva_2 basis in kw
F_1	Maximum core loss at LV_1
C	Maximum copper loss on a kva_2 basis in kw
CH	Maximum copper loss on a kva_2 basis in high voltage winding
CL	Maximum copper loss on a kva_2 basis in low voltage winding
CH_1	Same as CH except at LV_1
CL_1	Same as CL except at LV_1
CT_1	Total copper loss in kw at LV_1 ($= CH_1 + CL_1$)
T_1	Total loss in kw at LV_1 ($= F_1 + CT_1$)
V/T	Volts per turn
M	Correction factor in core loss (See Eq. 11)
N	Value from Figure 3 used in determining kva_2 (See Eq. 1)
P	Value from Figure 3 used in determining kva_2 (See Eq. 1)
GPM_1	Required water in gal. per min. to cool transformer at LV_1
FOW	Type of cooling—forced oil, water cooled (oil pump and oil-to-water heat exchanger)
OW	Type of cooling—water cooled (internal water cooling coils)

[1] Assume constant.

[2] ASA ambients are assumed, 25 C for OW and FOW units and 30 C for OA and FOA units—see ASA 12-00.111 and .112. Other ambients require special consideration. If rated (nameplate) kva is at average copper rise temperatures other than 55 C rise, such rated kva's must be corrected by multiplying them by the following factors to get them on a 55 C rise basis.

For 50 C rise multiplying factor is 1.08
For 45 C rise multiplying factor is 1.18
For 40 C rise multiplying factor is 1.30

TABLE I
CORRECTION FACTOR FOR IRON LOSS

Ratio LV_1/LV	M
1.0	1.000
0.95	0.901
0.90	0.826
0.85	0.783
0.80	0.735
0.75	0.676
0.70	0.625
0.65	0.578
0.60	0.540
0.55	0.504
0.50	0.473
0.45	0.411
0.40	0.348
0.35	0.285
0.30	0.222

Intermediate values are obtained by interpolation.

For a 3 phase unit

$$C = 43.5 + \left(\frac{\text{kva}_2 \times 4.03}{1000}\right) \qquad \text{Eq. 9}$$

For a 1 phase unit

$$C = 36.0 + \left(\frac{\text{kva}_2 \times 3.44}{1000}\right) \qquad \text{Eq. 10}$$

Finding core loss variations

Excitation at position Z in Figure 1, resulting in a low voltage of LV, will determine the maximum flux density in the core. The relationship between excitation and core loss is not directly proportional since the saturation curve is not a straight line. The type of core iron and the density at LV determine the individual correction factors to be used with different ratios of LV_1/LV. A correction factor M will give the iron loss, F_1, at any required low voltage LV_1.

$$F_1 = \frac{LV_1}{LV} \times M \times F \qquad \text{Eq. 11}$$

Typical values of M for different LV_1/LV ratios are given in Table I.

Finding copper loss variations

The copper loss, C, will vary because of a change in winding resistance, or a change in current magnitude. If it is assumed that temperature changes have a negligible effect upon the resistance, only the high voltage winding need be considered for changes in resistance since the number of turns in this winding is varied. Both the high voltage and low voltage windings must be considered for varying copper loses because of changes in current magnitude. It can be assumed that the total copper loss, C, of the transformer, as calculated from Eq. 9-10, is divided equally between the high voltage and low voltage windings, and may be expressed as

$$\frac{C}{2} = CH = CL \qquad \text{Eq. 12}$$

The high voltage copper loss, corresponding to any low voltage, LV_1, is varied by two factors; shown as Factors 1 and 2. Reference to Figure 2 is made for the variations and relative magnitudes of high voltage winding currents. Changes in CH resulting from turns resistance variations can be determined by a direct comparison between the total high voltage winding, equated to LV_3, as compared to the percent of high voltage winding in the circuit at any tap comparable to LV_1. Figure 4 shows the relation of the windings. To obtain LV_1 on the low voltage winding, the volts per turn, V/T, must now be LV_1/LV_3 times the V/T at LV_3. Since the voltage applied to the high voltage winding should be considered constant for any one set of calculations, an increase in low voltage from LV_3 to LV_1 can only be accomplished by changing high voltage taps and thereby increasing the V/T. To obtain LV_1 on the low voltage, the percentage of total turns on the high voltage winding, X percent, will be 100 percent divided by $\frac{LV_1}{LV_3}$. Since the resistance of the winding, and therefore, the copper loss, is directly proportional to the turns; the variance in the copper loss of the high voltage winding at low voltage LV_1, can be obtained using

$$\frac{LV_3}{LV_1} \qquad \text{Factor 1}$$

Because of the currents directly proportioned to the kva's, the factor accounting for the variance in CH for changes in high voltage windings currents may be obtained by using the square of the kva ratios

$$\left(\frac{\text{kva}_1}{\text{kva}}\right)^2 \qquad \text{Factor 2}$$

The copper loss, being an I^2R loss, is also directly proportional to the square of the current ratios

$$\left(\frac{LV_1}{LV_2}\right)^2 \qquad \text{Factor 3}$$

Applying Factors 1 and 2 at LV_1 to CH will determine CH_1

$$CH_1 = CH \times \frac{LV_3}{LV_1} \times \left(\frac{\text{kva}_1}{\text{kva}}\right)^2 \qquad \text{Eq. 13}$$

Because kva rating is constant and $\frac{\text{kva}_1}{\text{kva}} = 1$

for values of LV_1 equal to, or above LV_2, Eq. 13 may be simplified to

$$CH_1 = CH \times \frac{LV_3}{LV_1} \qquad \text{Eq. 14}$$

For values of LV_1 below LV_2, Eq. 13 may be changed since the kva rating, kva_1 under this condition is directly proportional to LV_1, to

$$CH_1 = CH \times \frac{LV_3}{LV_1} \times \left(\frac{LV_1}{LV_2}\right)^2 \qquad \text{Eq. 15}$$

Changes in the low voltage winding copper loss, C_1, are solely determined by current magnitudes in this winding since the actual number of turns do not change. Referring to Eq. 12, C_1 is again found using

$$CL = \frac{C}{2} \qquad \text{Eq. 16}$$

CL is at it's maximum value and remains constant for all LV_1 values equal to LV_2 and below since the low voltage current is maximum and constant at these voltages. Therefore under this condition, Eq. 16 can be expanded to

$$CL_1 = CL = \frac{C}{2} \qquad \text{Eq. 17}$$

At low voltages of LV_1 above LV_2, CL is reduced and must be corrected by the factor of

$$\left(\frac{LV_2}{LV_1}\right)^2 \qquad \text{Factor 4}$$

For this condition

$$CL_1 = CL \times \left(\frac{LV_2}{LV_1}\right)^2 \qquad \text{Eq. 18}$$

The total copper loss CT_1, at any low voltage value of LV_1, is the sum of the high and low voltage winding copper losses

$$CT_1 = CH_1 + CL_1 \qquad \text{Eq. 19}$$

By using Eq. 12, 13 and 18, Eq. 19 can be expanded to

$$CT_1 = \frac{C}{2}\left[\frac{LV_3}{LV_1} \times \left(\frac{\text{kva}_1}{\text{kva}}\right)^2 + \left(\frac{LV_2}{LV_1}\right)^2\right] \qquad \text{Eq. 20}$$

Determining total loss

The total loss, T_1, at any low voltage value LV_1, is equal to the sum of the core loss, F_1, and the copper loss, CT_1.

$$T_1 = F_1 + CT_1 \qquad \text{Eq. 21}$$

CT_1 should be considered for relative values of LV_1, which separate themselves into the following three cases. Some factors previously obtained which were shown to affect copper losses will not do so under all of these cases.

CASE 1 LV_1 equal to or above LV_2, Eq. 20 is (See Eq. 14)

$$CT_1 = \frac{C}{2}\left[\frac{LV_3}{LV_1} + \left(\frac{LV_2}{LV_1}\right)^2\right] \qquad \text{Eq. 22}$$

and total loss T_1 is

$$T_1 = \left(\frac{LV_1}{LV} \times M \times F\right) + \frac{C}{2}\left[\frac{LV_3}{LV_1} + \left(\frac{LV_2}{LV_1}\right)^2\right] \qquad \text{Eq. 23}$$

CASE 2 LV_1 equal to or below LV_2, Eq. 20 is (See Eq. 15)

$$CT_1 = \frac{C}{2}\left[\frac{LV_3}{LV_1} \times \left(\frac{LV_1}{LV_2}\right)^2 + 1\right] \qquad \text{Eq. 24}$$

and total loss T_1 is

$$T_1 = \left(\frac{LV_1}{LV} \times M \times F\right) + \frac{C}{2}\left[\frac{LV_3}{LV_1} \times \left(\frac{LV_1}{LV_2}\right)^2 + 1\right] \qquad \text{Eq. 25}$$

CASE 3 LV_1 equal to LV_2, Eq. 20 can be simplified to

$$CT_1 = \frac{C}{2}\left(\frac{LV_3}{LV_2} + 1\right) \qquad \text{Eq. 26}$$

and total loss T_1 is

$$T_1 = \left(\frac{LV_2}{LV} \times M \times F\right) + \frac{C}{2}\left(\frac{LV_3}{LV_2} + 1\right) \qquad \text{Eq. 27}$$

Furnace transformers, using reactors to obtain part of the LV_1 values, will require special consideration. The values of LV_1 and LV used in Eq. 11 must be determined on the bases of high voltage winding taps only and not on actual low voltages which may be obtained by reactor taps. The actual reactor total losses must be calculated separately for various LV_1 values and added to the total loss, T_1, of the transformer.

All of the foregoing losses are based on the transformer carrying full nameplate load kva at low voltages of LV_2 and above and maximum possible reduced loads at low voltages below LV_2. At each of these conditions, the transformer is carrying its maximum possible rated load.

If reduced loads are considered, the copper losses must be adjusted. The core loss, Eq. 11, will not require modification and will remain constant for any specific low voltage regardless of the loading. All copper losses, however, must be adjusted by multiplying each by

$$\left(\frac{\text{kva}_3}{\text{kva}_1}\right)^2 \qquad \text{Factor 5}$$

Water requirements are based on total losses

Since most furnace transformers are type OW or FOW, cooling water is required. The amount of water in gallons per minute required at any low voltage of LV_1 may be closely estimated using

$$GPM_1 = T_1 \times 0.378 \qquad \text{Eq. 28}$$

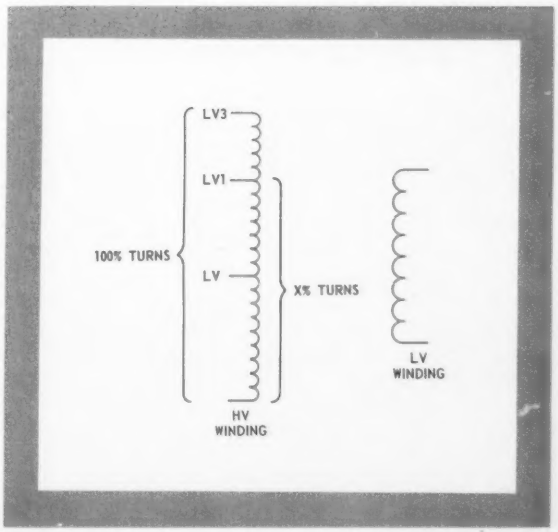
If reduced loading is considered, losses should be adjusted, see Factor 5, accordingly before being used in Eq. 28. Maximum loss T_1 and maximum water requirement occur when $LV_1 = LV_2$ and

$$GPM_1 = \left[\left(\frac{LV_2}{LV} \times M \times F\right) + \frac{C}{2}\left(\frac{LV_3}{LV_2} + 1\right)\right] \times 0.378 \qquad \text{Eq. 29}$$

The quantity of water determined from these equations will result in approximately a 10 C rise in cooling water temperature.

The determination of furnace transformers losses is complicated because voltage variations of the low voltage, unlike standard transformers, are accomplished with a tapped extended high voltage winding. These equations provide an accurate and easy method of obtaining the necessary loss transformer information required for determining overall furnace efficiency. ◆

COPPER LOSS is proportional to primary turns. **(FIGURE 4)**



CHARTING BREAKER RESERVE CAPABILITY

by **A. E. KILGOUR**
Power Systems Engineering
Allis-Chalmers Mfg. Co.

Quick review of breaker reserve capacity is often called for before any change in system short circuit capacity is contemplated. Graph shows years present breakers will be adequate.

OFTEN A FAST EVALUATION of interrupting equipment is needed when contemplating modification to present substations or when planning new substations. With a few charts, a curve and a knowledge of circuit breakers and system short circuit capacities, prediction of when changes will be necessary can be made quickly.

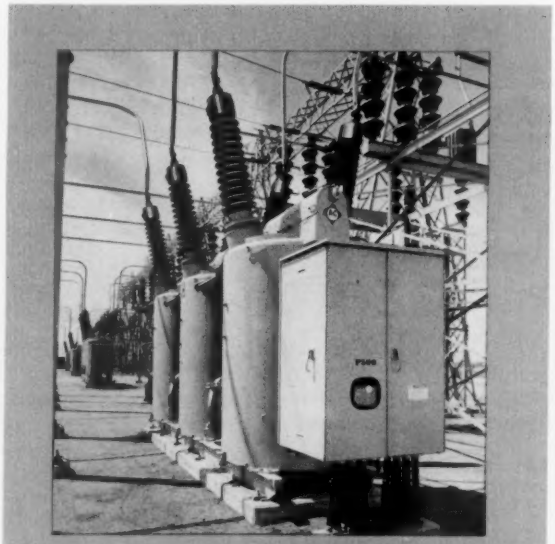
For convenience, charts have been prepared for the four general types of circuit breakers. Each chart corresponds to the standard circuit breaker ratings in accordance with the specified AIEE, ASA or NEMA Standards.

Chart I is for Indoor Oil Circuit Breakers, Chart II is for Indoor Oilless Circuit Breakers, Chart III is for Outdoor Oil Circuit Breakers, and Chart IV is for Outdoor Oilless Circuit Breakers.

The procedure for applying and using these charts is shown below:

How to use charts

1. Determine present maximum symmetrical system short circuit mva.
2. Select nearest standard breakers for the system.
3. Calculate ratio of $\frac{\text{Breaker rated mva}}{\text{Max. short circuit mva}}$

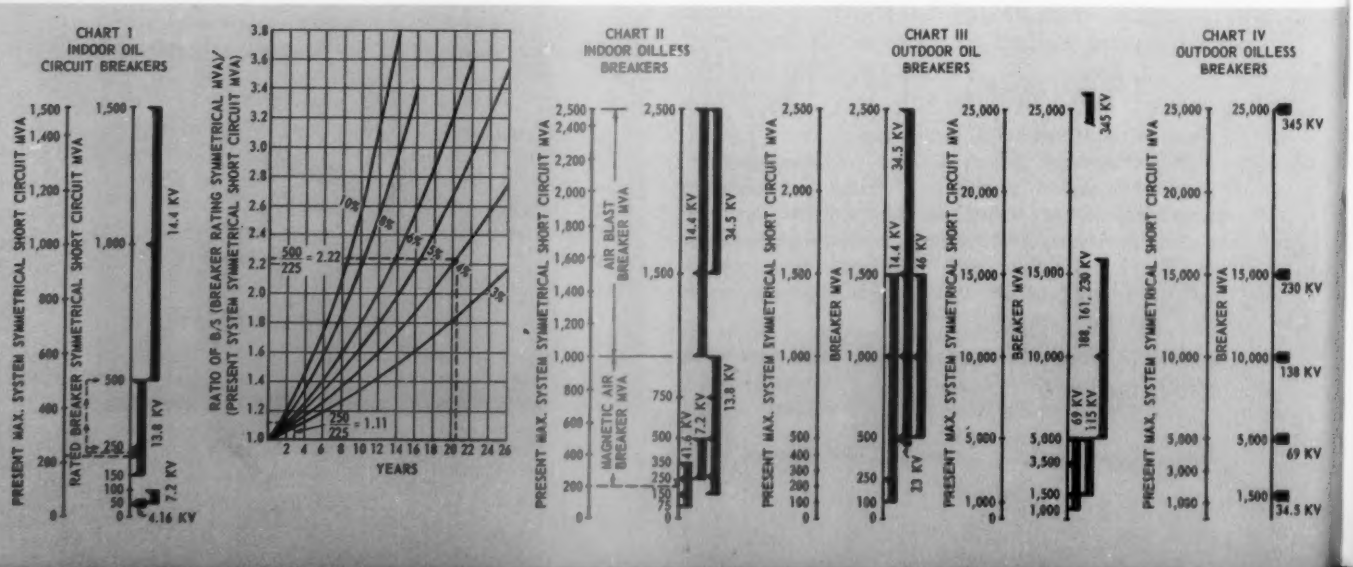


REASONABLE GROWTH of system short circuit mva is allowed for when planning substations. These 138-kv, 1600-amp, 10,000-kva circuit breakers were selected for southern system.

4. Determine from the growth rate curve the number of years of adequate breaker capacity.

Example shows method

Assume 225-mva maximum short circuit on 13.8-kv system and that indoor oil breakers with a four percent per year system growth are used. The nearest higher standard rated breaker, from Chart I, is 250 mva. Ratio is $\frac{250}{225} = 1.11$ which according to Figure 1 is low for reasonable system growth. The next higher breaker rating is 500 mva giving a ratio of $\frac{500}{225} = 2.22$ which according to Figure 1 allows for reasonable system growth of over 20 years. ◆



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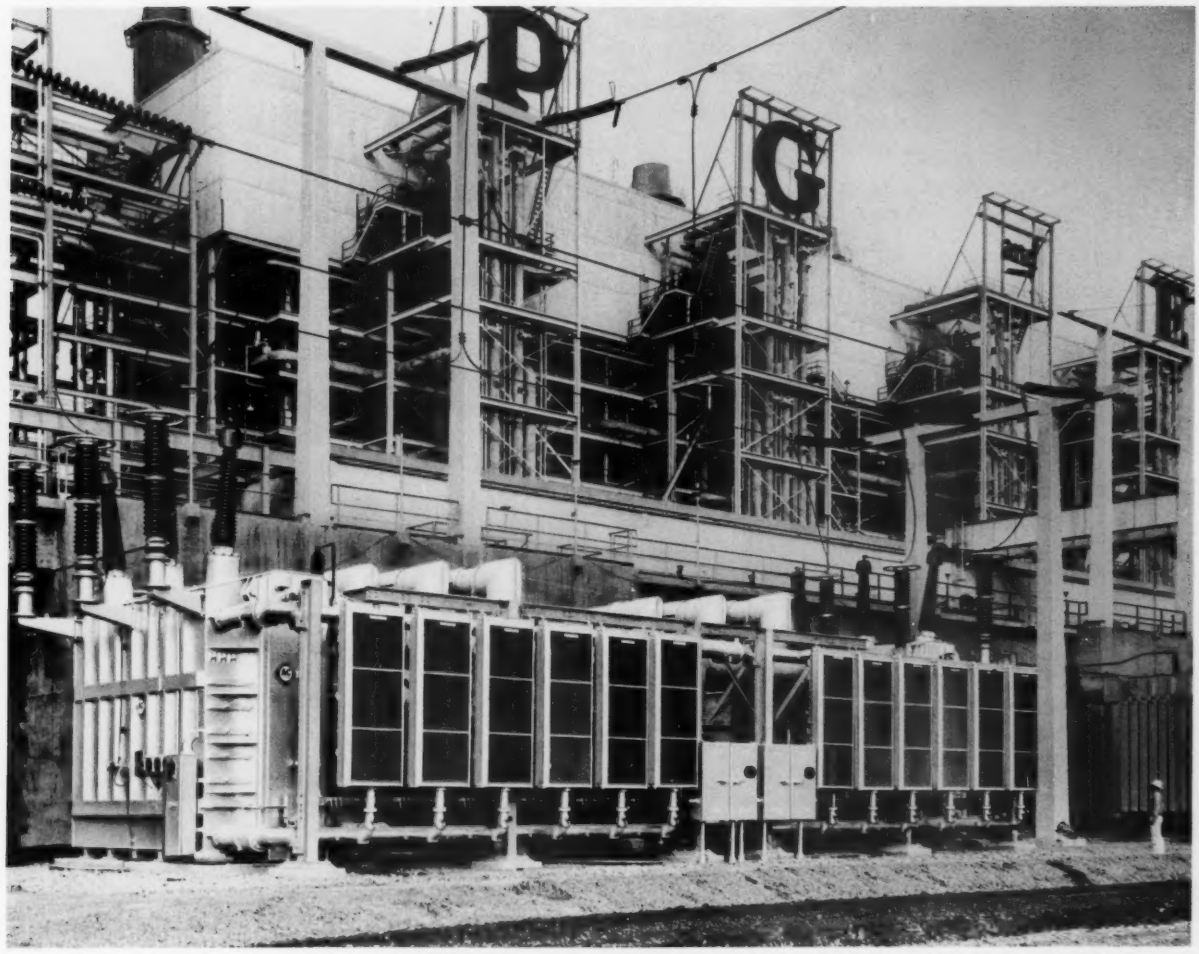

Dual-Cooled transformers at Pittsburg, California, Station of the Pacific Gas & Electric Company.

Hidden transformer capacity uncovered!

Dual-Cooled* transformers boost emergency capacity 33% without loss of life

Dual-Cooled transformers — an A-C development — are utilized at this central station to permit two-thirds of the turbine output to be carried in the event one transformer is off the line. In an emergency, cooling equipment from both units is connected to the functioning transformer. Result: Capacity of either unit with dual-cooling is increased one-third over its normal rating.

For substations under gradual load growth conditions, the *Dual-Cooled* transformer capacity bonus can defer purchase of additional units. Smaller transformers can be installed without paying for little-used standby capacity. You save on installation costs, on real estate, fencing, concrete and taxes.

Dual-Cooled transformers are available in any rating from 20,000 kva up. Contact your conveniently located A-C office or write **Allis-Chalmers,** Power Equipment Division, Milwaukee 1, Wisconsin.

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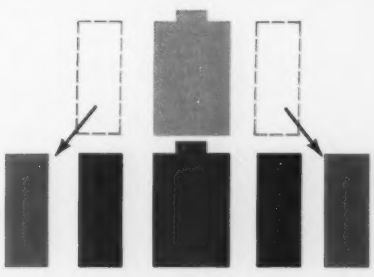

Another method of dual-cooling is the physical transfer of coolers from one transformer to the other.

SCIENCE OF HIGH SPEED ROTOR DESIGN ADVANCED

The proximity pickup is becoming a vital tool in the already highly developed science of designing and producing high speed turbine-generators. A typical hot-balance pit set-up of a generator rotor is shown with proximity pickup instrumentation.

This instrumentation is providing useful information on complex three-dimensional shaft deflection patterns throughout the operating speed range. It supplements conventional vibration pick-up instrumentation located at all bearings and on overhung portion of the shaft. Whereas conventional vibration detection equipment depends on contact with the vibrating member to generate a signal, proximity pickups need only be near the vibrating member to measure its vibration.

Output of each proximity pickup is fed into modern electronic equipment, producing simultaneous permanent records of all monitored vibrations at selected locations along the rotor. This information not only determines the shaft critical speeds, but it also reveals the configuration assumed by the shaft at any desired speed. Correlating these results with computer studies, the design engineers are able to better determine certain empirical constants necessary for future designs.

Although intended to provide basic information on generator rotor vibration modes for development of larger capacity units, this instrumentation has also been found to be extremely useful in production balancing. Generator rotors up to 49 ft. in length and over 100 tons in weight can be precision balanced and tested to 120 percent of rated speed. To increase sensitivity, bearing pedestals are mounted on adjustable-flexibility supports. The carefully regulated temperature, lubrication, and electrical equipment permit precise determination of operating characteristics.

This expanding program of intensive research in mechanical performance of generator rotors augments earlier benefits of the hot-balance pit, now in its fifth year of regular use. Knowledge being gained by advanced procedures and precision instrumentation is furthering greatly the development of larger high speed synchronous generators.

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